AD-A110 538   EARTH SATELLITE CORP WASHINGTON D C
              EXPERIMENTAL ASSESSMENT OF IMPROVED SPATIAL RESOLUTION LANDSAT --ETC(U)
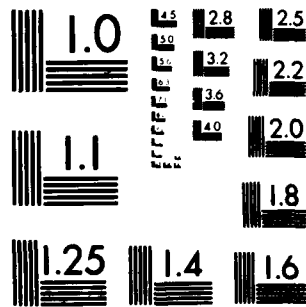   SEP 81 C SHEFFIELD, M PLACE, D GAROFALO
                                                        DAAK70-80-C-0016
UNCLASSIFIED E/S-1234
                                            ETL-0268   NL

1.0

1.1

1.25

2.8 2.5
3.2 2.2
3.6
4.0 2.0

1.8

1.4 1.6

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

(2) LEVEL II

ETL-0268

AD A110538

Experimental assessment of
improved spatial resolution /
Landsat data

C. Sheffield

M. Place

D. Garofalo

J. Dykstra

L. Hall

DTIC
SELECTED
FEB 5 1982
B

Earth Satellite Corporation
7222 47th Street (Chevy Chase)
Washington, D.C. 20015

SEPTEMBER 1981

82 01 261

U.S. ARMY CORPS OF ENGINEERS
ENGINEER TOPOGRAPHIC LABORATORIES
FORT BELVOIR, VIRGINIA 22060

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ETL-0268	2. GOVT ACCESSION NO. AD-AJJO53	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) EXPERIMENTAL ASSESSMENT OF IMPROVED SPATIAL RESOLUTION LANDSAT DATA.		5. TYPE OF REPORT & PERIOD COVERED FINAL REPORT.
		6. PERFORMING ORG. REPORT NUMBER E/S 1234
7. AUTHOR(s) C. Sheffield, M. Place, D. Garofalo, J. Dykstra, L. Hall		8. CONTRACT OR GRANT NUMBER(s) DAAK70-80-C-0016
9. PERFORMING ORGANIZATION NAME AND ADDRESS EARTH SATELLITE CORPORATION 7222 47TH STREET (CHEVY CHASE) WASHINGTON, D. C. 20815		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Engineer Topographic Laboratories Geographic Sciences Laboratory Fort Belvoir, Virginia 22060		12. REPORT DATE September 30, 1981
		13. NUMBER OF PAGES 71
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Landsat, Seasat, Digital Image Processing, Return Beam Vidicon, Multispectral Scanner, Shoreline Mapping, Lake and Stream Delineation, Agricultural Patterns, Roads and Bridges, Urban Area Delineation, Swamp and Marsh Delineation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the possible uses of higher resolution (25 meter) space-derived images for delineating and measuring surface features of interest in the Corps of Engineers' Civil Works Program. Following a discussion of imaging sensors and computer processing methods, test evaluations are described in which Landsat multispectral scanner data and SEASAT SAR data were interpreted for surface features. The comparative advantages of the two data sources are discussed, and the complementary nature of Landsat MSS and SEASAT SAR images

DD ,FORM, 1473 EDITION OF 1 NOV 65 IS OBSOLETE

is displayed in the image analyses. Image examples are included for both background discussion and test site evaluation.

Accession For	
NTIS GRA&I	✔
DTIC TAB	☐
Unannounced	☐
Justification	

PER CALL JC

By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A	

DTIC
COPY
INSPECTED
2

PREFACE

This report was prepared under contract DAAK70-80-C-0016 for the
U. S. Army Corps of Engineers, Engineer Topographic Laboratories, Fort
Belvoir, Virginia.

We would like to acknowledge the assistance and contribution to
this project of the Contracting Officer's Technical Representatives,
Mr. Lawrence P. Murphy and Mr. Laslo Greczy, in obtaining and making
available to us image tapes and collateral test area data for project
performance.

EXECUTIVE SUMMARY

This report describes the analysis of Landsat and SEASAT data of
the Elizabeth City and Duck coastal areas of North Carolina, with an
evaluation of its potential use in Corps of Engineers' civil works pro-
grams. The main application areas are in shore-line mapping, lake and
stream delineation, swamp and marsh delineation, urban area delineation,
and the mapping of roads, bridges, and agricultural field patterns.

The report is structured as follows:

Section I describes the background for the study, with reference
to the upcoming launch of Landsat-D. Following a description of relevant
spacecraft and sensors in Section I·, Section III describes the correction
and enhancement processes applied on this project to image data in magnetic
tape format. Section IV reviews the spaceborne data types available for
project evaluation, and Section V lists these and the associated airborne
and ground truth data bases. In Section VI the main interpretation results
using Landsat and SEASAT data are described, comparing both data sources
and their limitations. The conclusions to be drawn from this work are
given in Section VII and recommendations for future simulations are in
Section VIII.

A brief description of the processing system used on the project is
contained in Appendix 1.

CONTENTS

FIGURES

TABLES

EXPERIMENTAL ASSESSMENT OF IMPROVED SPATIAL
RESOLUTION LANDSAT DATA

I.   BACKGROUND - REASON FOR THE STUDY

Evaluation of Landsat data, and its potential application to a
variety of land-based and coastal problems, began with the launch of
ERTS-1 (now Landsat-1) in 1972. Over the past nine years investigators
have become quite familiar with the uses and limitations of the Multi-
spectral Scanner, which is the primary Landsat data source, and familiar
to a lesser degree with the properties of Return Beam Vidicon data.
Digital processing of magnetic tape data from Landsat has progressed a
great deal in the same period, and enhancement and classification tech-
niques continue to broaden the possible uses of the data received from
Landsat-1, -2, and -3.

In 1982, the launch of Landsat-D will signal the arrival of the next
generation of earth resources satellites. This new generation will be
characterized by a number of improvements: spectral range will be extended,
spectral resolution will be improved, spatial resolution will sharpen, more
intensity levels will be measured, more frequent ground coverage will be
possible, and stereo images will become available. All these capabilities
do not reside in a single satellite. The characteristics of Landsat-D,
SPOT, ERS, and the proposed instruments of Mapsat, Stereosat and Shuttle
Imaging Radar (SIR) are briefly described in the next section.

In order to gain a better understanding of the way in which the new
instruments will prove useful to Corps of Engineers' programs, the U.S. Army
Engineer Topographic Laboratories in 1980 initiated a study project to
evaluate certain elements of the new generation of satellites' performance,
utilizing for this purpose combinations of available satellite imagery,
supported for evaluation purposes by ground truth and aerial instrument
coverage.

-1-

The results of this study are reported here. Following a summary discussion of spacecraft systems and sensors, computer processing methods to handle digital data tapes are described as they have been employed on this project. This is followed by a review and critique of the available data sources. Specific interpretations are provided for two North Carolina test sites, employing Landsat digital data, SEASAT digital data, and a complete supporting aerial data base and ground truth survey. Emphasis in the interpretation was placed upon certain key areas of Corps of Engineers civil works, as follows:

Shoreline and Inlet Mapping & Studies

Dredging Deposit Detection

Lake and Stream Delineation

Swamp and Marsh Delineation

Urban Area Delineation and Studies

Roads, Related Patterns and Bridges

Agricultural Field Line Patterns

Following these results, this report provides an overall evaluation, with suggestions for possible additional work by the Corps of Engineers using Landsat-D simulated data.

Project Chronology

As originally conceived, it was intended that this study would make use of the Landsat-3 Return Beam Vidicon data,* which, with its 30 meter resolution, should approximate the degree of detail visible on a Landsat-D

---

*See Section II for the description of this and other relevant sensors and spacecraft.

image, although without of course possessing the corresponding spectral range.

In the first months of the project, considerable effort was made to obtain Landsat-3 digital RBV tapes, which could be manipulated on the computer to yield enhanced products. When tapes of suitable test areas were finally obtained, their quality was a great disappointment. The apparent resolution of the images, even after enhancement, looks far inferior to 30 meters (examples are shown in Section IV). It was therefore decided to modify the approach to the study, and to employ SEASAT Synthetic Aperture Radar (SAR) as the higher resolution data source in place of Landsat-3 RBV. This introduces some complication in analysis because, whereas Landsat multispectral scanner and RBV data have approximately the same geometry (particularly if the images have been acquired at the same time), by contrast, SEASAT SAR data and Landsat MSS data are considerably distorted geometrically with respect to each other. The problems this introduces, and the approach used to overcome them, are described in Section VI.

II.   PLATFORMS AND SENSORS

The emphasis in this section is on properties of the Landsat-D space-
craft, and properties of the Landsat-1, -2 and -3 and SEASAT systems that
were used in the analysis for the project. For completeness, brief
summaries are also provided here of several other systems, past and future,
which because of their resolution or spectral range provide relevant informa-
tion on the possible appearance and use of Landsat-D data.

A.   Landsat-1, -2, and -3 Spacecraft

1.   Orbit

Three Landsat spacecraft have so far been launched by
NASA. Each of them moves in a sunsynchronous orbit with 103
minute period, inclination 99°, eccentricity close to zero, and
mean semi-major axis 7,290 kilometers. The mean altitude of the
spacecraft is thus about 910 kilometers.

Observations of the earth are made on the daylight side
(see note below on Landsat-3 thermal channel), which is traversed
on the descending node of the orbit with mean local equatorial
crossing time of 9:30 a.m. Each satellite provides imagery for
complete coverage of the earth's surface in latitudes lower than
81° every 18 days. Landsat-1 was launched in July 1972, Landsat-2
in January 1975, and Landsat-3 in March 1978. Landsat-1 is no
longer functioning.

2.   Multispectral Scanner

The primary observing instrument on Landsat-1, -2, and
-3 has been a Multispectral Scanner (MSS), with instantaneous field

of view of approximately 79 meters by 79 meters on the surface
of the earth. Observations are made in four spectral ranges:

0.5 - 0.6 micrometers (visible yellow);

0.6 - 0.7 micrometers (visible red);

0.7 - 0.8 micrometers (infrared Band 1); and

0.8 - 1.1 micrometers (infrared Band 2).

These four bands are conventionally termed Bands 4, 5, 6, and 7
for reasons described below. Oversampling the analog electrical
signal from the MSS produces in the digital telemetry picture
elements that are each approximately 57 meters by 79 meters.
The swath width on the ground covered by the scanner is 185 kilo-
meters wide, and for convenience of processing the swath is
divided in the satellite along-track direction into 185 kilometer
portions, with each resulting 185 by 185 kilometer picture element
array being termed one scene or frame.

The observed ground reflectances are quantized to 64
reflectance levels in each spectral band. Although ground process-
ing of the images later assigns reflectances to a range of 256 grey
levels, it should be noted that the number of discernibly different
grey tones in an image is no more than 64. The overall information
flow for MSS imagery is shown in Figure 1. Data from the MSS
sensors is available in both image (film and print) and Computer
Compatible Tape forms.

Note concerning the Landsat-3 Thermal Channel: Landsat-3
carried a fifth channel in thermal infrared, with a spectral range

FIGURE 1 - General Information Flow for Processing of Landsat MSS Images

Information is telemetred to a ground station when the satellite is in 'line of sight' position; otherwise, data is stored on board until the satellite is in proximity of a station. On the ground, information is processed and stored on film or computer tape

Data sent electronically to receiving station

Scanned image stored as an array of 'picture elements' (pixels)

Enlarged representation of pixels

Each pixel corresponds to about one acre on the ground

Each scene is an array 2,340 by 3,240 pixels

Computer-stored array of reflected brightness in four separate bands

Images can be additionally modified by computer processing

Producton of colour prints

Digital-to-photo format

BLUE

GREEN

RED

FILTERS

B&W POSITIVES

COLOUR NEGATIVES

THREE-BAND COMPOSITE COLOUR NEGATIVE

FALSE COLOUR COMPOSITE PRINT

from 10.4 to 12.6 micrometers, and an instantaneous field of view of 240 meters by 240 meters. This instrument was intended to prov' de thermal imagery on either day side or night side passes. However, one of the two detectors for this sensor failed immediately upon launch, and no data from the instrument was ever released by NASA for general evaluation.

3. Return Beam Vidicon

Ninety-eight percent of the data processed from the Landsat spacecraft to date has been multispectral scanner (MSS) data. However, in addition to the scanner, the first two Landsat spacecraft also carried a second imaging system, a 3-camera Return Beam Vidicon (RBV) with spectral ranges 0.475 to 0.57, 0.58 to 0.68, and 0.7 to 0.83 micrometers. Problems with the spacecraft unrelated to actual RBV performance meant that little RBV data was obtained on either Landsat-1 or Landsat-2. Images from the RBV were intended to constitute Bands 1, 2 and 3 of Landsat data, hence the number assignment of the MSS bands.

Landsat-3 carries a different form of RBV consisting of two panchromatic cameras (spectral range 0.505 to 0.750 micrometers) mounted side by side in the spacecraft and each imaging a square of 98 Km^2. They have an image overlap of 14 Km, and four Landsat-3 RBV images cover roughly the same area as a single MSS scene. However, the discernible ground field of view of the RBV is signifi-cantly better than that of the MSS, and for a medium contrast scene, resolution is about 30 meters.

Like the MSS data, the RBV data from Landsat-3 is also available in either film or Computer Compatible Tape form. However, considerable difficulties were experienced during this project in obtaining good quality digital tapes of RBV data. Image samples are presented in Section IV of this report.

B. Landsat-D

1. Orbit

Landsat-D is planned for a launch in the Fall of 1982. It, and its identical successor Landsat-D', will be in sun-synchronous orbits, rather lower in height than Landsat-1, -2, and -3, with a mean height of 705 Km. Like earlier Landsat's the inclination of the orbit will be about 99°. Landsat-D will have a repeat ground coverage of 16 days rather than the 18 days of Landsat-1, -2, and -3. Selection of the lower orbit was initially justified to permit Space Shuttle retrieval. However, this will not be possible until Vandenberg Shuttle launches begin about 1986. Like the earlier Landsat's, Landsat-D images the day side of the earth during the descending node of the orbit with mean equatorial crossing time of 9:30 a.m.

2. Multispectral Scanner

Landsat-D will carry a redesigned MSS, which will have identical spectral ranges and spatial resolution to the instruments flown on the first three Landsat spacecraft. This MSS will be the prime instrument in providing data continuity in the program.

3. Thematic Mapper

The Thematic Mapper will be the prime instrument in providing experimental products from Landsat-D. The assessment of the potential value of Thematic Mapper data is the prime objective of the present project.

The Landsat-D Thematic Mapper (TM) will observe in seven spectral ranges as follows:

0.45 - 0.52 micrometers (visible blue-green)

0.52 - 0.60 " (visible yellow)

0.63 - 0.69 " (visible red)

0.76 - 0.90 " (first infrared, sensitive to vegetation density)

1.55 - 1.75 " (sensitive to leaf water content and separates clouds from snow)

2.08 - 2.35 " (sensitive to altered [mineralized] rock); and

10.4 - 12.5 " (thermal band)

Each of the first six of these has a ground resolution of 30 meters, and the seventh (thermal) band has a ground resolution of 120 meters. The Thematic Mapper will permit observation at 256 discrete quantization levels as compared with the 64 levels of Landsat-1, -2, and -3. The Thematic Mapper, like the MSS, is a scanning instrument, but unlike the MSS it performs two-direction scans. A hardware scanline corrector on the spacecraft permits data registration.

C. SEASAT

1. Orbit

The SEASAT-1 spacecraft was launched in June 1978 and failed in October 1978 as a result of a major electrical short circuit; thus only three and a half months of collected data are available. The spacecraft moves in a nearly circular orbit, at a mean altitude of 800 km and an inclination of 108°.

Although primarily designed for the observation of oceanic phenomena, SEASAT recorded data over many land areas, particularly in the United States. The spacecraft carried five major sensors, only one of which, the Synthetic Aperture Radar (SAR), is of interest to the present project.

2. SEASAT Radar

The radar on the SEASAT spacecraft is a synthetic aperture instrument deriving its imaging capability through the forward motion of the spacecraft. The instrument operates at a frequency of 1.27 GHz (23.5 centimeter wavelength), and data processed at full resolution has a ground field of view of about 25 meters and a swath width of 100 Kms. Reconstruction of an image from the original radar signal is a substantial task, and interpretations made for this project (see Sections IV and VI) suggest to EarthSat interpretation staff that even the best resolution SEASAT data available for this project does not possess resolution as good as 25 meters.

Since radar is an active device, providing its own scene illumination, different parts of a SEASAT radar scene display different obliquities in illumination angle. This complicates the interpretation process, as does the fact that ground reflectances in the microwave region differ markedly from the familiar visible or near-infrared reflectances. Comparison of results obtained from the interpretation of SAR data with those obtained from Landsat is therefore a complex task. This question is discussed in more detail in Section VI.

SEASAT SAR images contain a distortion in the across-track direction owing to the varying range distance between spacecraft nadir and the target point. For digitally processed images, picture element size varies because of this from 14.8 meters in the far across-track range to 19.4 meters in the near across-track range. Along-track picture element size is roughly constant at 16 meters. This variability of within-scene scale also adds some complexity to the interpretation problem, particularly in registering SEASAT with other data sources.

D. SPOT

As mentioned earlier, Landsat-D represents only the first of a series of new earth sensing satellites. One of the most significant of the new instruments is the French SPOT system (Système Probatoire d'Observation de la Terre), scheduled for 1984 launch. The SPOT satellite has a nominal altitude of 822 Km, a sunsynchronous orbit, and a repeating ground track period of 26 days. The two

observing instruments on board are Multiple Linear Arrays (MLA),
with panchromatic (0.51 - 0.73 micrometers), 10 meter resolution,
and with color (0.5 - 0.59, 0.61 - 0.69, and 0.79 - 0.90 micro-
meters) 20 meter resolution. The satellite will also have the
capability to swing the mirrors of one or both of the observing
instruments up to 26° sideways from the nadir, thereby permitting
stereo imaging of any portion of the earth's surface (below 81°
in latitude) utilizing successive days of coverage. In addition,
sideways viewing permits coverage of a particular area of interest
on an average of every 2-1/2 days.

SPOT lacks the extended spectral range of Landsat-D,
but its very high resolution makes it a contender for a variety
of applications that currently use airphoto coverage.

There appear to be no U.S. plans for a civilian
Multiple Linear Array instrument that could be flown earlier
than 1988.

E. Other Future Satellites

A number of other high resolution satellite systems have
been proposed for flight in the next few years. They will be des-
cribed here only in the briefest summary.

Mapsat is a 10 meter resolution stereo mapping satellite pro-
posed by the U.S. Department of the Interior. It would have three
spectral bands (0.47 - 0.57, 0.57 - 0.70, and 0.76 - 1.05 micro-
meters) and be designed as the name suggests primarily for map

making and particularly digital terrain modeling. The program
is proposed but not approved.

Stereosat is a system proposed by the GEOSAT Committee for
use in geological exploration. It would provide a 15 meter
resolution panchromatic (0.5 - 0.9 micrometers) stereo capa-
bility. The project has been designed but does not have current
funding.

The Large Format Camera to be flown on the Space Shuttle
will provide capability similar to that of SPOT, namely, 10 meter
resolution in black and white, and 20 meter ground resolution
using color film. Currently the system is assigned to the OSTA-3
shuttle payload, tentatively designated to be flown in August 1984.
Since this instrument will be carried on the Shuttle, images will
be restricted to latitudes below 45°.

The Shuttle Imaging Radar (SIR) is a synthetic aperture, L-
band radar with a proposed ground resolution of about 38 meters.
Like the Large Format Camera, it will not be able to provide high
latitude ground coverage.

F.   Other Relevant Spaceborne Systems

Three other satellites and sensors should be mentioned
briefly. These are systems which have already been flown and
which, either spectrally or spatially, could offer information
about the probable performance of Landsat-D.

The Coastal Zone Color Scanner is a 6 channel scanning
instrument with narrow spectral windows (0.43 - 0.45, 0.51 - 0.53,

0.54 - 0.56, 0.66 - 0.68, 0.70 - 0.80, and 1.05 - 1.25 micro-
meters) extending from the blue to the shortwave infrared.
However, although spectrally the instrument provides analogs
to Landsat-D wavelengths, its coarse resolution of 825 meters
omits so much detail that direct comparisons with Thematic
Mapper data are probably not meaningful.

Similarly, the Advanced Very High Resolution Radiometer
(AVHRR), despite its name, has a ground resolution of 1 kilometer.
Despite its interesting spectral properties (0.55 - 0.66, 0.725 -
1.10, 3.55 - 3.93, and 10.5 - 11.5 micrometers), it too is not
a useful tool for Thematic Mapper comparisons when scene detail is
important.

Finally, the S190A and S190B cameras carried on the Skylab
missions in 1973 provided black and white, natural color, and color
infrared images with roughly 30 meter resolution. Although the
degree of detail visible on Skylab photography is excellent, its
non-digital nature and non-systematic coverage of the earth makes
it almost useless for assessments of the type conducted here. The
S192 13-channel scanner carried by Skylab might seem to offer a
more useful tool for digital comparisons. However, the S192 data
with its conical scan pattern and high image noise make it too
difficult to use in work of this type, even though its resolution
is very close to that of the Landsat MSS (68 x 72 meter picture
element).

The main characteristics of the sensors described in this
section are summarized in Tables 1 and 2.

Table 1

Resolution and spectral distribution for resource satellites, 1972-1984

Instrument	Ground Field of View	Spectral Distribution	Status
Multi-Spectral Scanner[1] (Landsat 1, 2, 3 and D)	79 meters (sampled to 57 x 79 meter pixel)	0.5 - 0.6 µm 0.6 - 0.7 0.7 - 0.8 0.8 - 1.1	Flown
Return Beam Vidicon[1] (Landsat 1 and 2)	65 meters (medium contrast scene; little data available from these instruments)	0.475 - 0.57 µm 0.58 - 0.68 0.70 - 0.83	Flown
Return Beam Vidicon[2] (Landsat-3)	30 meters (medium contrast scene)	0.505 - 0.90 µm	Flown
Thermal Infra-Red[2] Channel (Landsat-3)	240 meters (Note: data from this sensor was never re-leased)	10.4 - 12.6 µm	Flown
SEASAT Synthetic[3] Aperture Radar	25 meters (data only from July to October, 1978)	1.27 GHz	Flown
Coastal Zone Color Scanner[3]	825 meters	0.43 - 0.45 µm 0.51 - 0.53 0.54 - 0.56 0.66 - 0.68 0.70 - 0.80 1.05 - 1.25	Flown
AVHRR (Advanced Very High Resolution Radio-meter on NOAA-6)	1000 meters	0.55 - 0.68 µm 0.725 - 1.10 3.55 - 3.93 10.5 - 11.5	Flown
Thematic Mapper[4] (Landsat-D)	30 meters 120 meters	0.45 - 0.52 0.52 - 0.60 0.63 - 0.69 0.76 - 0.90 1.55 - 1.75 2.08 - 2.35 10.4 - 12.5	For Fall 1982 Launch
SPOT[5]	20 meters 10 meters	0.50 - 0.59 µm 0.61 - 0.69 0.79 - 0.90 0.50 - 0.75	For 1984 Launch
Stereosat[6,7] (Proposed, but no approved program)	15 meters (tentative)	0.5 - 0.9 µm (tentative)	Flight Date Unknown
Mapsat (Proposed, but no approved program)	10 meters	0.47 - 0.57 µm 0.57 - 0.70 0.76 - 1.05	Flight Date Unknown
ERS (Japanese system, details not yet available)	Not specified	Visible, infrared, thermal infrared, and radar	Proposed 1986 Launch

Table 2

SKYLAB CHARACTERISTICS

S190A Film Characteristics

Wavelength (μm)	Film	Dynamic Resolution On the Ground (m)
0.5-0.6	PAN-X B&W (SO-022)	30
0.6-0.7	PAN-X B&W (SO-022)	28
0.7-0.8	IR B&W (EK 2424)	68
0.8-0.9	IR B&W (EK 2424)	68
0.5-0.88	IR Color (EK 2443)	57

S192 Scanner Characteristics

Channel	Spectral Bandwidths (μm)
1	.41 - .46
2	.46 - .51
3	.52 - .56
4	.56 - .61
5	.62 - .67
6	.68 - .76
7	.78 - .88
8	.98 - 1.09
9	1.09 - 1.19
10	1.20 - 1.30
11	1.55 - 1.75
12	2.10 - 2.35
13	10.20 - 12.50

III. COMPUTER PROCESSING

A. Properties of Data

The principal data sources used on this project are the Landsat Multispectral Scanner data, the Landsat-3 Return Beam Vidicon data, and the SEASAT-1 Synthetic Aperture Radar data. Although there are substantial differences between images obtained from these three instruments, there are many processing similarities. In particular, the following applies to all three images:

(1) Received data from the satellite is via telemetry, thus all images are constructed from an initially digital (PCM) signal.

(2) Images are synoptic, with a single image covering 10,000 square kilometers (RBV and SEASAT SAR) or 34,000 square kilometers (Landsat MSS).

(3) The telemetered information, as recorded on magnetic tape, retains a greater dynamic range than can be expressed on any single piece of film. Opportunities for "tuned" products, emphasizing one class of information at the expense of others, therefore exist. Enhancement must be performed in computer processing prior to the creation of a photographic product, if tuned products are to be provided.

(4) Images from all data sources depart from orthophoto geometry, though each in different ways. MSS data, because it is provided by a scanner and images different parts of a scene at different times, contains dis-

-17-

tortions due to earth rotation and mirror sweep

effects; RBV data contains image tube distortion

effects; and SAR data is distorted by range

variations (SEASAT radar obliquities vary between

17 and 23 degrees away from the nadir at the near-

range and far-range limits).

In addition, all data sources share common distortions caused
by earth curvature, finite viewing distance and terrain variation.
It is necessary to compensate for all of these effects in some way
if comparative analysis is to be performed.

B.   Image Correction and Enhancement

Although there is overlap between the two categories, it is
productive to regard the processing of space-imaged data in two
parts: correction and enhancement. Within these two categories
it is also useful to distinguish two forms: radiometric processing
and geometric processing. Each of the four possible subcategories
will be discussed separately.

1.   Radiometric Corrections

These corrections are important only in the case of
Landsat MSS data where multiple detectors are used in sensing the
ground scene.   Each spectral band of MSS data is recorded using
six separate detectors, mounted side by side so that a
single sweep of the scan mirror provides six parallel traverses
of the terrain. Since each detector has a slightly different
response to incoming radiation,   the uncorrected image made from

raw data will display a characteristic "striping" or "banding" with a spatial frequency of 474 meters (6 x 79).

Elimination of striping may be attempted in two different ways. One method is to calibrate the six on-board detectors of each spectral band against a standard on-board source of illumination. The other method matches to each other the frequency histogram of reflectance values obtained from each of the six detectors. Both methods are currently in use by different groups. In EarthSat's experience, the technique of matched histograms is superior to attempted on-board calibration, and the former method has been used in the work of this project.

During the radiometric correction process, the grey level range for Landsat MSS data is expanded from 64 to 256, to permit a finer relative adjustment of grey levels from the six detectors in each band. An example of a Band 7 Landsat MSS image before and after striping is shown in Figures 2A and 2B.

No analog of this problem exists for either RBV or SEASAT SAR data. Although not a radiometric distortion in the usual sense, SEASAT data has another peculiarity which affects image appearance. Whereas the visible and near-IR radiation seen by Landsat contains all polarizations, SEASAT was operated in a single polarization mode, namely that of a horizontally polarized signal and horizontally polarized sensed return.

FIGURE 2A

870CT76 C N37-22/W114-47 N N37-21/W114-42 MSS 7 D SUN EL38 AZI49 190-8701-G-I-N-D-IL NASA ERTS E-2824-17275-7 01

FIGURE 2B

Radar reflected signals are terrain dependent. In rough terrain, horizontal and vertical polarization measurements are almost equal. In smooth terrain, horizontal-polarization measurements from unpolarized incident radiation will be up to 15 db below vertical-polarization measurements.[8] When the horizontally polarized signal from SEASAT SAR meets the ground, it is depolarized to varying degrees depending on the terrain. Part of the reflected signal will be vertically polarized. As a result, the energy of return signal to an instrument that senses only horizontally polarized radiation is reduced, and the reduction is terrain-dependent. These effects are observed, for example, when radar images are produced of crops and plant communities with pronounced vertical orientation. Photographic examples illustrating horizontal-horizontal and horizontal-vertical signal and sensed returns may be found in Reference 9 (Page 1,000).

2.   Radiometric Enhancement

The histogram obtained from a typical spaceborne data source (see Figure 3 for an example) usually consists of a pronounced peak with rapidly diminishing tails. Often, subtantial parts of the original grey level range are unpopulated or nearly so. If an image is produced directly from such a distribution it lacks contrast and is a poor tool for interpretation.

Computer processing can be used to modify the histogram before an image is created, so that it occupies all the available grey level range and thus improves the useful contrast of the result. This type of differential contrast adjustment is usually called a "stretch algorithm." Using digital processing, very general contrast adjustments are possible. Many different stretch algorithms have been developed. The most commonly used are probably the linear stretch, in which the given histogram is uniformly stretched to occupy the full grey level range; and the histogram equalizing stretch, in which the most populated grey levels are the most separated from their neighbors. These two stretches are shown in diagrammatic form in Figure 4.

A generalized version of these two types of contrast stretch, termed a hybrid stretch, has been developed by EarthSat and is our most commonly used technique for contrast adjustment. In a hybrid stretch, the population in each grey level value of the histogram is weighted by a power (P) of the occupancy number at that grey level. This permits linear stretches (P=0) and histogram

FIGURE 3 - SAMPLE HISTOGRAM BEFORE CONTRAST ADJUSTMENT
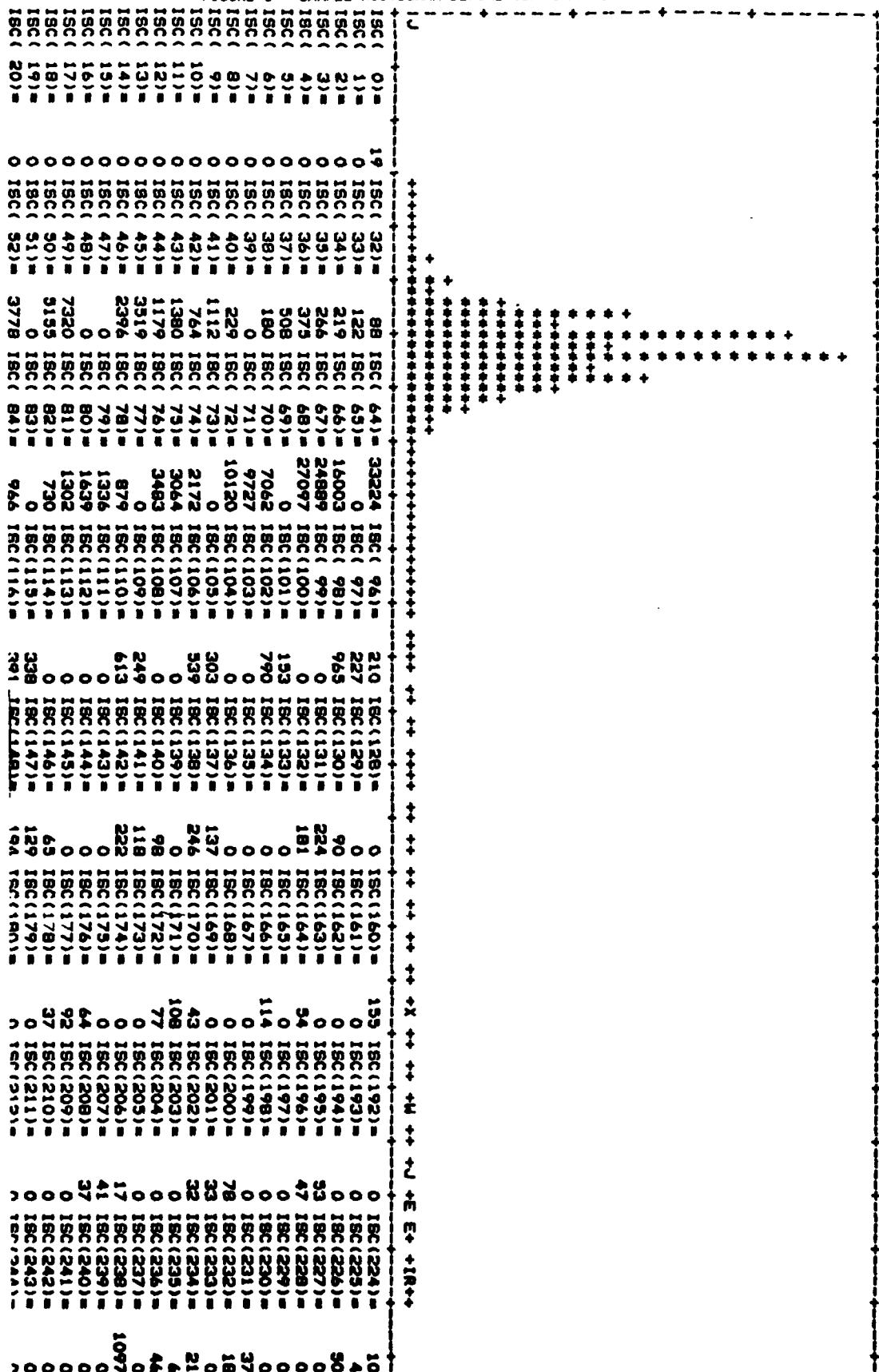
FIGURE 4A - Effect of the Linear Stretch

HISTOGRAM OF ORIGINAL IMAGE BEFORE GREY LEVEL STRETCH

GREY LEVEL MAPPING

FINAL IMAGE HISTOGRAM
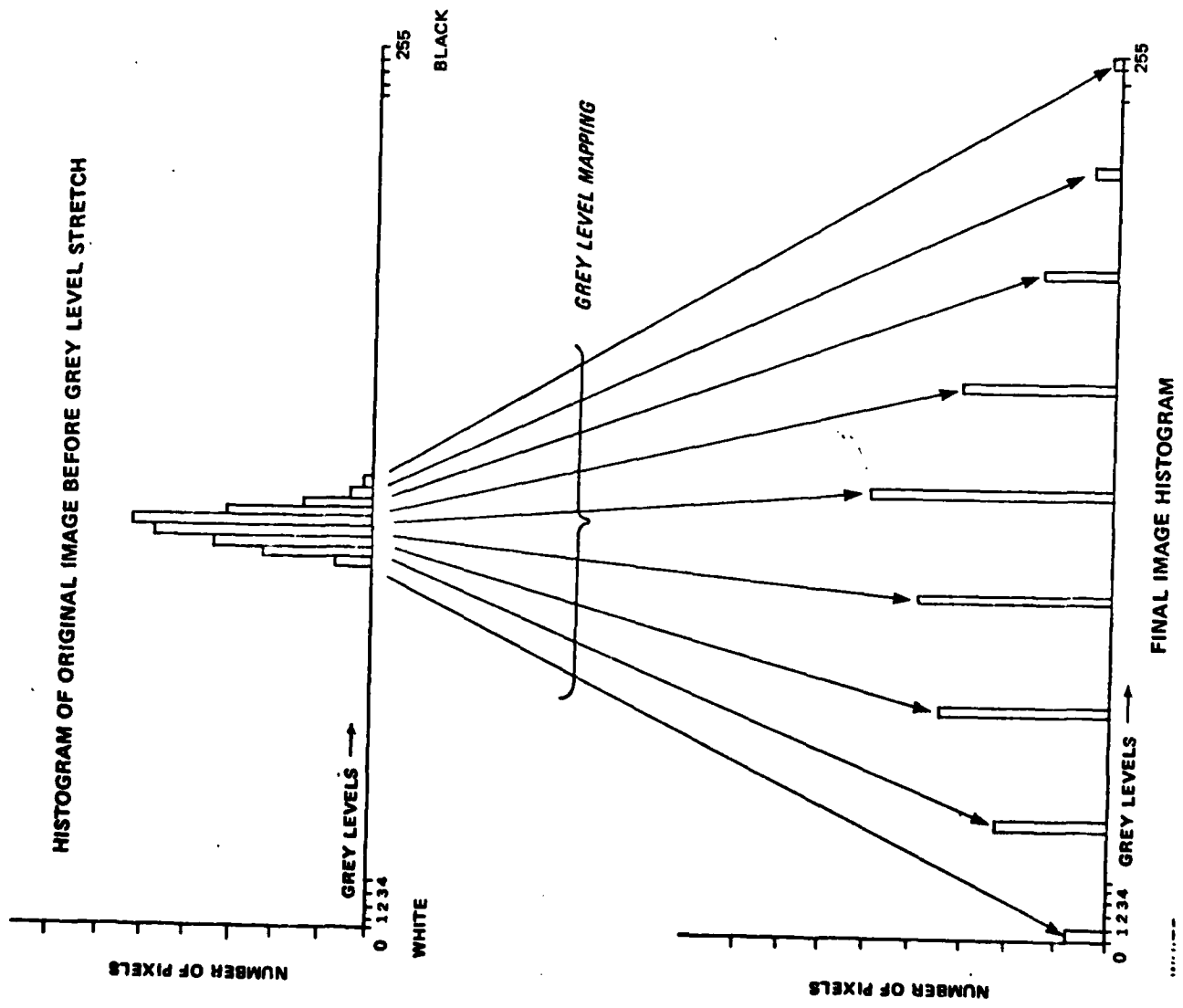
FIGURE 4B - Effect of the Histogram Equalizing Stretch
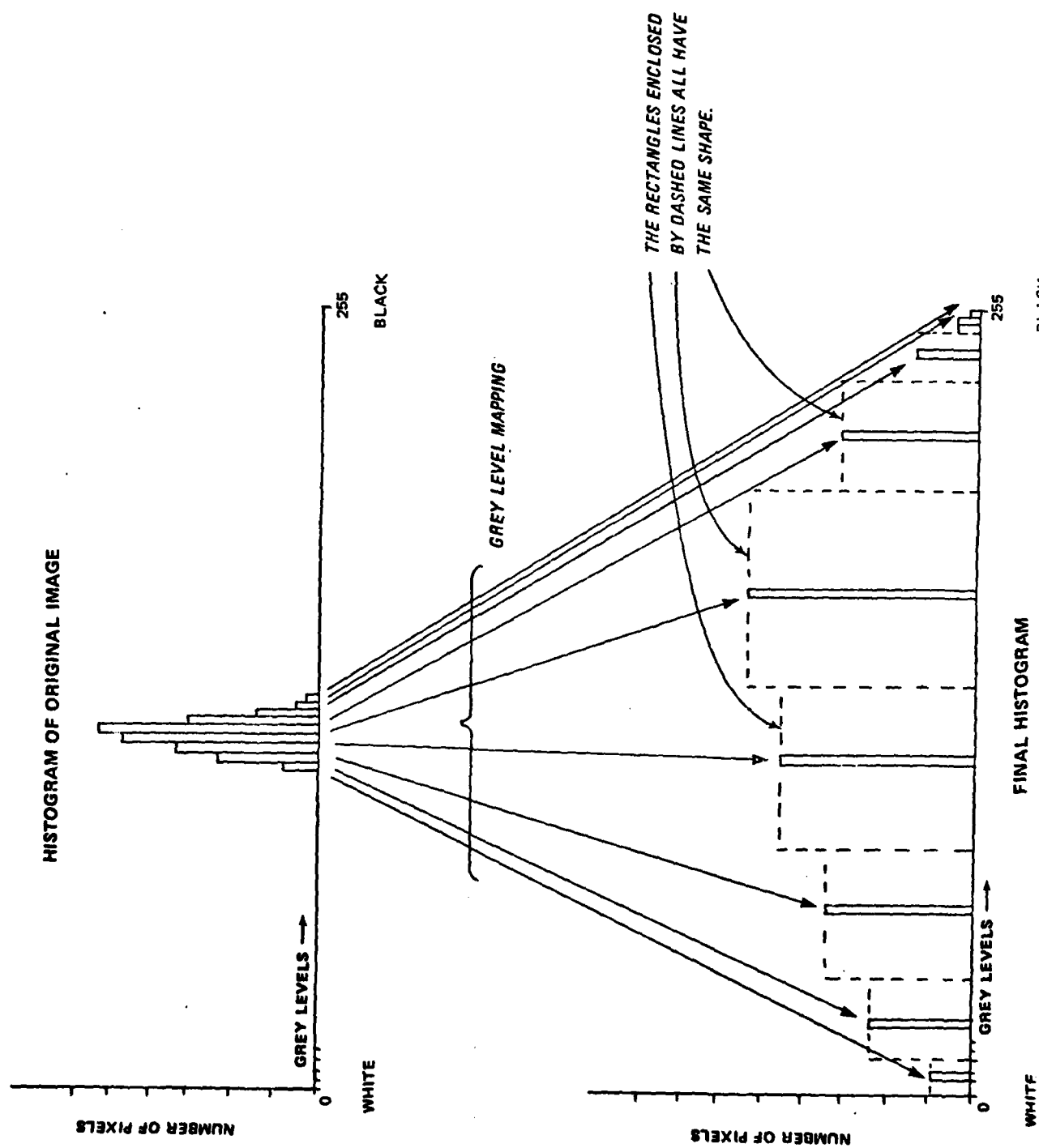
equalizing stretches (P=1.0), plus numerous intermediate stretch procedures (0<P<1). Contrast adjustment using hybrid stetches was performed on all the image data examples discussed in Sections IV and VI. The histogram of Figure 3 after a hybrid stretch with P=0.7 is shown in Figure 5.

3. Geometric Corrections

Principal geometric error sources in each data type

(a) Multispectral Scanner

- Earth rotation effect (Unlike a camera, a scanner takes a significant time to observe the area covered by one scene, and the earth's rotation during this time causes a skewing of the resulting image.)

- Earth curvature effects

- Finite altitude effects (Since the scanner has a look angle aperture of 5.76°, this introduces panoramic distortion which must be corrected.)

- Variations in scan mirror sweep velocity and scan mirror sweep angle produce variable scan-line length and changes within scanlines.

- Satellite height and sa :llite attitude produce differential scale effects in the along-track and across-track directions, and also produce additional skewing.

FIGURE 5 - HISTOGRAM AFTER USE OF HYBRID STRETCH (NOTE: RIGHT
AND LEFT DIRECTIONS ARE REVERSED FROM FIGURE 3)

EACH * = 2320

HISTOGRAM TABLE FOR SCANNED PICTURE AFTER GRAY SCALE PROCESSING

```
ISC(  0)= 1093    ISC( 32)= 0    ISC( 64)= 0
ISC(  1)=  153    ISC( 33)= 0    ISC( 65)= 0
ISC(  2)= 1192    ISC( 34)= 0    ISC( 66)= 0
ISC(  3)= 1011    ISC( 35)= 0    ISC( 67)= 0
ISC(  4)=  267    ISC( 36)= 0    ISC( 68)= 7062
ISC(  5)= 1222    ISC( 37)= 0    ISC( 69)= 0
ISC(  6)=  293    ISC( 38)= 0    ISC( 70)= 0
ISC(  7)=  869    ISC( 39)= 0    ISC( 71)= 0
ISC(  8)=  554    ISC( 40)= 0    ISC( 72)= 0
ISC(  9)=  966    ISC( 41)= 0    ISC( 73)= 0
ISC( 10)=  730    ISC( 42)= 0    ISC( 74)= 0
ISC( 11)= 1302    ISC( 43)= 0    ISC( 75)= 27097
ISC( 12)= 1639    ISC( 44)= 0    ISC( 76)= 0
ISC( 13)=    0    ISC( 45)= 0    ISC( 77)= 0
ISC( 14)= 1336    ISC( 46)= 0    ISC( 78)= 0
ISC( 15)=  879    ISC( 47)= 0    ISC( 79)= 0
ISC( 16)=    0    ISC( 48)= 0    ISC( 80)= 0

ISC( 96)= 0    ISC(128)= 16003    ISC(160)= 0
ISC( 97)= 0    ISC(129)= 0        ISC(161)= 0
ISC( 98)= 0    ISC(130)= 0        ISC(162)= 0
ISC( 99)= 0    ISC(131)= 0        ISC(163)= 50429
ISC(100)= 0    ISC(132)= 0        ISC(164)= 0
ISC(101)= 0    ISC(133)= 0        ISC(165)= 0
ISC(102)= 0    ISC(134)= 0        ISC(166)= 0
ISC(103)= 0    ISC(135)= 0        ISC(167)= 0
ISC(104)= 0    ISC(136)= 0        ISC(168)= 0
ISC(105)= 0    ISC(137)= 18452    ISC(169)= 0
ISC(106)= 0    ISC(138)= 0        ISC(170)= 0
ISC(107)= 33224 ISC(139)= 0       ISC(171)= 0
ISC(108)= 0    ISC(140)= 0        ISC(172)= 0
ISC(109)= 0    ISC(141)= 0        ISC(173)= 0
ISC(110)= 0    ISC(142)= 0        ISC(174)= 0
ISC(111)= 0    ISC(143)= 0        ISC(175)= 14844
ISC(112)= 0    ISC(144)= 0        ISC(176)= 0

ISC(192)= 0       ISC(224)= 7320
ISC(193)= 0       ISC(225)= 0
ISC(194)= 0       ISC(226)= 0
ISC(195)= 18548   ISC(227)= 2396
ISC(196)= 0       ISC(228)= 0
ISC(197)= 0       ISC(229)= 3519
ISC(198)= 0       ISC(230)= 0
ISC(199)= 0       ISC(231)= 1179
ISC(200)= 0       ISC(232)= 0
ISC(201)= 0       ISC(233)= 1340
ISC(202)= 0       ISC(234)= 744
ISC(203)= 0       ISC(235)= 1112
ISC(204)= 20029   ISC(236)= 409
ISC(205)= 0       ISC(237)= 883
ISC(206)= 0       ISC(238)= 607
ISC(207)= 0       ISC(239)= 194
ISC(208)= 0       ISC(240)= 0
```

-28-

Following geometric correction, each MSS
Landsat scene consists of a skewed array of
picture elements each 57 meters x 79 meters,
with roughly 3,240 picture elements along each
scanline and 2,340 scanlines in a full image.
Since each spectral band is generated by the
decomposition of a single radiation input stream
of ground reflectances, the four spectral bands
that constitute a Landsat scene are registered
with each other to an accuracy of a few meters.

NOTE: The above comments exclude discussion of
the Landsat-3 thermal band, for which, as noted
earlier, no data has ever been released.

(b) Landsat RBV data

Many of the sources of geometric distortion
here are common to both MSS and RBV images. Each
RBV camera records an area 99 Km x 99 Km; thus an
individual RBV scene is less affected by certain
distortions, notably earth curvature and panoramic
effects. RBV data requires correction for:

- Changes in satellite height and satellite
  attitude.
- Finite altitude effects.
- Earth curvature effects.

- Linear and non-linear screen distortion.

- Scale variation produced by long period
  changes in image size on the vidicon tube.

- Read-out variations in converting the TV
  image to a telemetry data stream.

Following geometric correction and resampling, a digital RBV data tape contains an array of 5,322 x 5,322 picture elements. It will be noted that although the resolution (for medium contrast scenes) of the Landsat-3 RBV instruments is about 30 meters, the digital tape is sampled at a spacing of 18.6 meters (99 Km ÷ 5,322). This oversampling implies very high correlation between neighboring picture elements, and encourages the use of smoothing algorithms in the geometric enhancement process.

(c) SEASAT SAR data

This is the most complicated of the data sources considered here, and also the one least within the control of the study. The basic signal is not in image format. As with any synthetic aperture instrument, an image must be reconstituted from a large number of successive radar reflectance signals.[10] This entire pre-processing is performed before a SEASAT digital tape is released to the user, and little information is provided with the tape

concerning the way in which geometric corrections
are performed during the pre-processing phase.
However, it is certain that the following factors
affect the geometric fidelity of the resulting
SEASAT SAR image:[11,12]

- Earth curvature effects.
- Changes in satellite height and satellite
  attitude.
- Panoramic distortion.
- Terrain elevation (This is a much more
  significant variable for SEASAT SAR data
  than for Landsat data because of the
  oblique look angle, which may be as much
  as 23° away from the vertical.)
- Across-track scale changes.
- Variations in satellite velocity (which
  are critically important in the reconstitu-
  tion of an image from the raw radar signals).
- Earth rotation effects (The radar image is
  constructed from radar return signals taken
  over a 20 second period.)

The geometrically corrected SEASAT SAR image
(for which no range correction has been performed)
consists of an array of 6,144 x 6,144 picture elements,
covering a ground area of 100 Km x 100 Km.

4. Geometric Enhancement

The contrast adjustments described in Section III.B.2
are applied to the whole scene, and they do not employ any local
spatial information about the scene in computing new grey level
values for each picture element. In local edge enhancement and
smoothing operations, on the other hand, the grey level adjust-
ment at any picture element depends upon the grey level of
spatially neighboring picture elements. Edge enhancement is
used to increase the visibility of features of small spatial
extent within an image, whereas smoothing is used to reduce the
effects of electronic noise within an image.

Landsat MSS and RBV and SEASAT SAR data call for sub-
stantially different enhancement operators. Both MSS and RBV
data are oversampled in creating digital tapes (the RBV to a
greater extent than the MSS). Neighboring picture elements are
therefore highly correlated in information content, and good
opportunities exist for image sharpening, by the use of edge
enhancement operators. In the case of RBV data, however, sub-
stantial electronic noise works to reduce the advantage of edge
enhancement. EarthSat's experiments suggest that MSS data
almost always benefits from edge enhancement, but that digital
RBV data does not. SEASAT SAR, which like all radar imagery is
highly monochromatic, has much electronic noise (which may in fact be
statistical effects due to photon limitation) and displays the
characteristic scintillation patterns of a radar image. In such
a case, the high-pass filter of edge enhancement operators would

create increased noise in the final image. To reduce image
noise, it is appropriate to employ low pass filter operators,
i.e., smoothing algorithms. This leads to a "cleaner" image,
but inevitably it degrades the apparent resolution of the
resulting image.

Figure 6 illustrates the effect of a particular
high pass filter (a 5-point Laplacian) on a good quality digi-
tal RBV image of California (compare with Figure 7).

It must be noted that both high and low pass filters
(edge enhancement and smoothing operators) distort radiometric
image properties, even when they increase the interpretability
of the image. This is not too important in manual photo-
interpretation, but becomes very significant if computerized
analysis methods (such as image classification algorithms) are
employed.

Images produced employing the radiometric and geometric
corrections and enhancements described above constitute the GEOPIC
processed version of Landsat images developed by Earth Satellite
Corporation. Color examples of such images are shown in Figures 11,
12 and 13 of Section IV. Additional details of GEOPIC production
and interactive processing of Landsat images are given in Section IV
and also in Appendix 1.

FIGURE 6

-34-
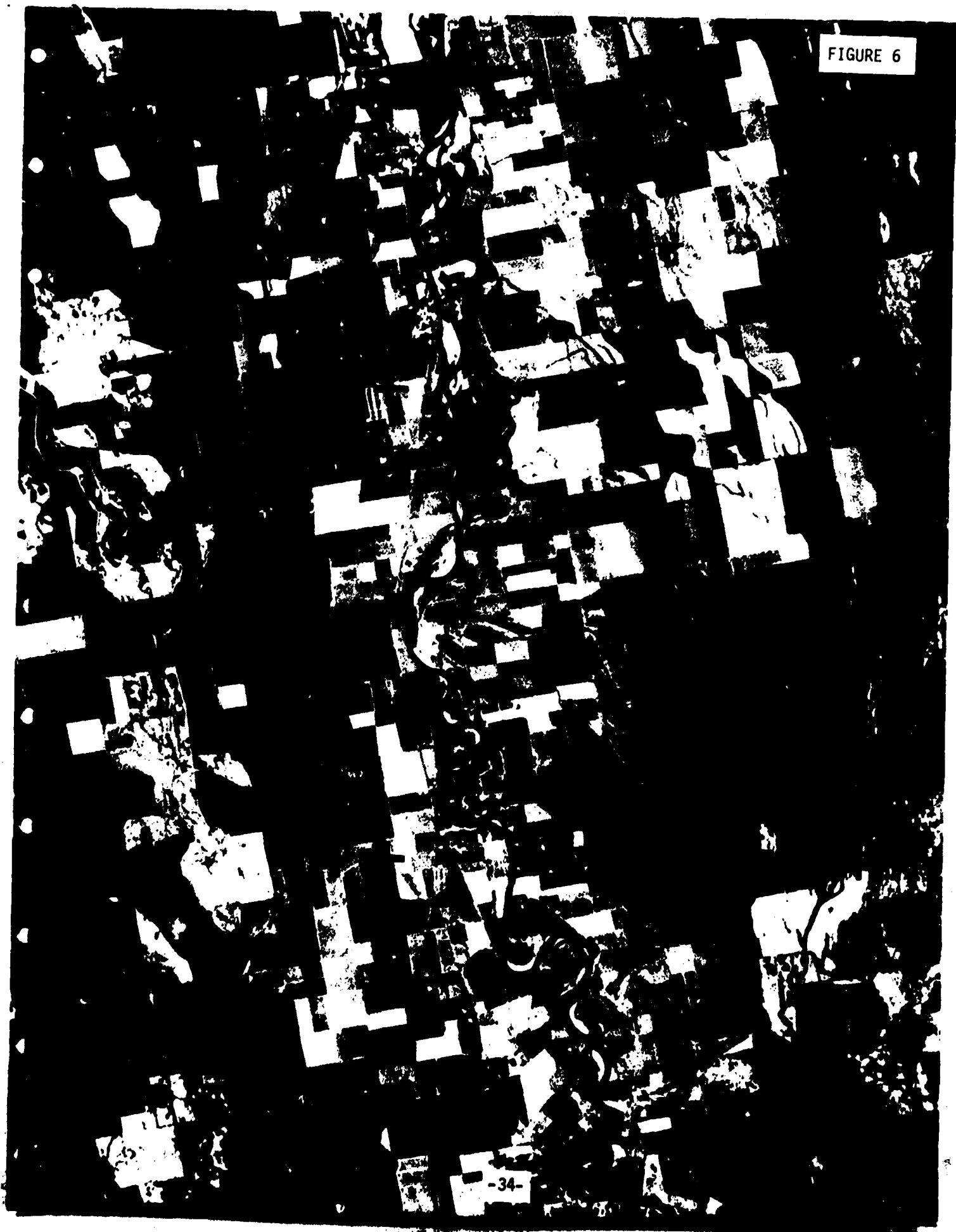
IV.   PROJECT EXPERIMENTS

In this section, general comments on the evaluation of different data types are provided, with a view to overall assessment of the quality and particularly the variability of relevant space-derived data. Experience shows that image quality, even when obtained under apparently identical conditions (height, sun angle, viewing angle, and weather), is frequently highly variable.

The evaluation of test site images specific to this study, rather than of general data sources, is given in the interpretation results of Section VI.

A.   Evaluation of Landsat Digital RBV Data

The first generally available digital RBV tape of Oroville, California, promised very high quality from this data source. The original impression was that, suitably combined in the computer with MSS data, digital RBV data would permit the construction of false color images with an apparent ground resolution approaching 30 meters. A computer processed example of the Oroville scene is given in Figure 7, and a MSS-RBV computer combination for the Washington, D.C. area forms Figure 8. Neither of these examples contains the main classes of land use of prime interest in this study; therefore, tapes of coastal areas in Mississippi and Louisiana were obtained.

The results of processing those examples with suitable contrast adjustment and intensity stretches are shown in Figures 9 and 10. The degree of detail visible in these examples does not approach that seen in the Oroville, California and Washington, D.C.
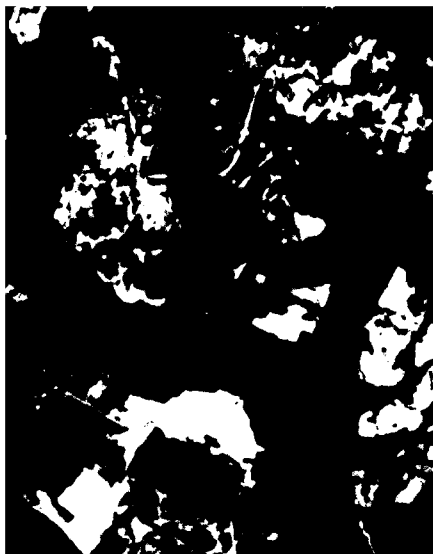
FIGURE 8

FIGURE 10

-39-

scenes. It is difficult to accept that the resolution of these
images is truly 35 meters, and in addition there were variations
in overall image intensity across the scene.

Following the evaluation of these test site examples, and
taking into account the difficulty and delays experienced in
obtaining even these test tapes, it was decided that continued
attempts to use digital RBV images as measures relevant to the
potential of Landsat-D Thematic Mapper data would not be fruitful.
Attention was therefore turned to the possible use of SEASAT SAR
data as a high resolution alternative to digital RBV data. The
interpretation described in Section VI uses Landsat and SEASAT
data only, supplemented for verification purposes by aerial photo-
graphy.

B.   Evaluation of Landsat MSS Data

Landsat MSS images are usually at their most striking in areas
of variegated land use, high relief, and exposed geology. Impressive
examples of MSS images in these three categories are given in
Figures 11, 12 and 13.

Generally speaking, images of coastal areas are flat, sedi-
mented, and often uniformly vegetated. One therefore expects that
Landsat MSS images for coastal application may appear less
immediately useful. However, the presence of the 0.5 - 0.6 micro-
meter band offers an advantage that neither the RBV nor SEASAT radar
possesses; namely, a fair ability to penetrate shallow water, or, in
turbid areas, the power to trace sediment plumes. Figure 14 shows

FIGURE 11

-41-

When you purchase **EarthSat Landsat Photomaps,** here's what EarthSat does:

- EarthSat selects the images to be used. Careful selection by professionals insures a minimum of cloud cover, reduces seasonal or annual image differences, and provides best available imagery coverage.

- EarthSat digitally processes and enhances the Landsat scenes, using the most advanced GEOPIC processing technology, to produce the best quality images for photomapping.

- EarthSat's experienced technicians process, color-balance, and mosaic the GEOPIC images, using existing maps or control for best-fit scaling and positioning.

- EarthSat works with you to design photomap legends, titles, and/or credit information appropriate to your needs.

- EarthSat formats the mosaics into a photomap series for your area of interest, and produces and delivers the desired quantity of photomap products.

EarthSat Landsat Photomaps can be produced in a variety of formats, scales, and materials to best suit your particular use or applications. Typical characteristics and applications include the following:

LANDSAT PHOTOMAP CHARACTERISTICS	**LANDSAT PHOTOMAP APPLICATIONS**
Superior Quality Color Landsat Images	Cartography — Landsat Images Become Landsat Basemaps
Same Format as Topographic or Other Maps	
Semi-controlled (fitted to established cartographic controls)	Natural Resources Analyses — Vegetation, Forestry, Agriculture, Geology, Water Resources, etc.
Geographical/Spatial Perspective	Land Use and Land Capability Analyses
Reproducible, Color or Black & White	Land and Energy Exploration Development
Multipurpose Flexibility and Economy	Transportation Facilities and Network Planning
Utilizes Existing and Current Data	Communication and Reference Base
Compatible with Other Planning and Cartographic Data	Education

LANDSAT MOSAICS

Mosaics provide a broad geographical overview of the physical resources and diverse environments of a nation or region. Prior to the launching of Landsat satellites, mosaics compiled from costly aircraft surveys were hampered by the lack of uniform lighting conditions which reduced detail and contrast of scene features.

Large area features and interrelationships of a nation's physical and cultural environments may be readily seen on Landsat Mosaics. They provide a vital communications tool for regional mapping, geographical studies, planning and multiple resource applications. They offer, for the first time, an opportunity to see the nation or region as it would be seen by astronauts, and in one view observe the relationships between the physical environment and the natural and cultural resources.

TECHNOLOGY TRANSFER

EarthSat is committed to developing advanced and cost-effective means for analyzing and understanding our Earth's resources, and to assist decision-makers in their programs to develop and manage our environment. Landsat Photomaps, Mosaics, and GEOPIC images are valuable tools, providing a superior data base for mapping, analysis, planning, and display.

EarthSat's Technology Transfer programs take many forms — each designed to meet specific needs and requirements, and to assess and improve local capabilities and expertise. These programs focus particularly on Developing Nations, by assisting local scientists, planners, engineers, and managers to make best use of Landsat and other remote sensing data, cartographic tools, analysis techniques, field surveys, etc., to understand, develop, and manage their nation's resources.

For more information concerning EarthSat Landsat Photomaps, prices, delivery schedules, technology transfer programs tailored to your needs and specifications, and other EarthSat services, call or write:

EARTH SATELLITE CORPORATION

41 A

FIGURE 12

-42-

FIGURE 13

-43-

GEOPIC PROCESSING

All GEOPIC images receive corrections for geometric and radiometric distortions in the raw digital Landsat data, unless otherwise specified, including —

- **Digital Edge Enhancement**

  Edge enhancement increases contrast of color and density along boundaries within an image. This process improves the analyst's ability to rapidly identify linear and border features such as agricultural field boundaries, land use interfaces, geologic faults, marked relief or structural changes, water body limits, soil type boundaries, lithologic changes, etc.

- **Gray Scale Adjustments**

  EarthSat's contrast enhancement algorithm stretches the range of reflectance values to maximize image information content. Gray scale adjustments can also be manipulated to visually highlight image areas of special interest.

- **Scan Line Removal**

  This unique algorithm suppresses regularly spaced scan lines (or "striping") in an image caused by repetitive malfunction of the satellite's multispectral scanner detectors. The process enhances image quality, eliminates processing of erroneous data, and greatly improves image interpretability.

- **Geometric Corrections**

  A series of algorithm improvements now result in maximum geometric accuracies in GEOPIC images. Systematic correction parameters include: satellite pitch, roll, yaw, heading, and altitude variations; image skew caused by both earth rotation (by latitude) and finite scan time; spectral band offsets; mirror scan velocity; and panoramic corrections for earth curvature. Scale accuracy is maximized in all directions for easy superimposition of overlay maps and charts.

- **Geographic Tick-Marks**

  30-minute latitude and longitude tick marks provide GEOPIC image users with approximate coordinates for convenient cartographic reference data. These tick marks are located using the ephemeral data supplied by NASA on the CCT's of each image.

GEOPIC images, produced from a digitally processed Landsat image (1068-17364) acquired on September 19, 1972, show the San Rafael Swell in eastern Utah at approximately 1:1,140,000 scale. At left is a standard False Color Infrared GEOPIC image; on the right is a GEOPIC Eigen image of the same scene.

43A

FIGURE 14

an example in which special digital processing has permitted
the mapping of submarine topography to depths of more than 30
feet using only the Landsat MSS data as source, in an area
where the water is clear. Although no data source is available
to support the statement, it seems highly probable that the
Thematic Mapper will be equally useful in the functions of sedi-
ment and bottom mapping. Pure, clear water is most penetrated
by light with 0.48 micrometers wavelength. Water which is more
turbid, because of suspended particulates, permits maximum light
penetration at longer wavelengths. Figure 15 shows the relation-
ship between optimal penetration wavelength and the presence of
suspended matter in the water. The MSS Band 4, from 0.5 - 0.6
micrometers, extends a little beyond the best wavelength for water
penetration, even in turbid areas. The Thematic Mapper has a
band from 0.45 - 0.52 micrometers that is perfectly situated
for penetration of clear water, and hence for the mapping of sub-
marine features. The distinction between return signals from
submarine features in clear water and from scattered radiation
in turbid water is not easy. In general, the two physical varia-
bles will be confused unless other information is available. This
subject is discussed further in Section VI.

C. Evaluation of SEASAT SAR Data

Radar instruments, sensing in the microwave region, show a
differentiated return (and hence image detail) through variations
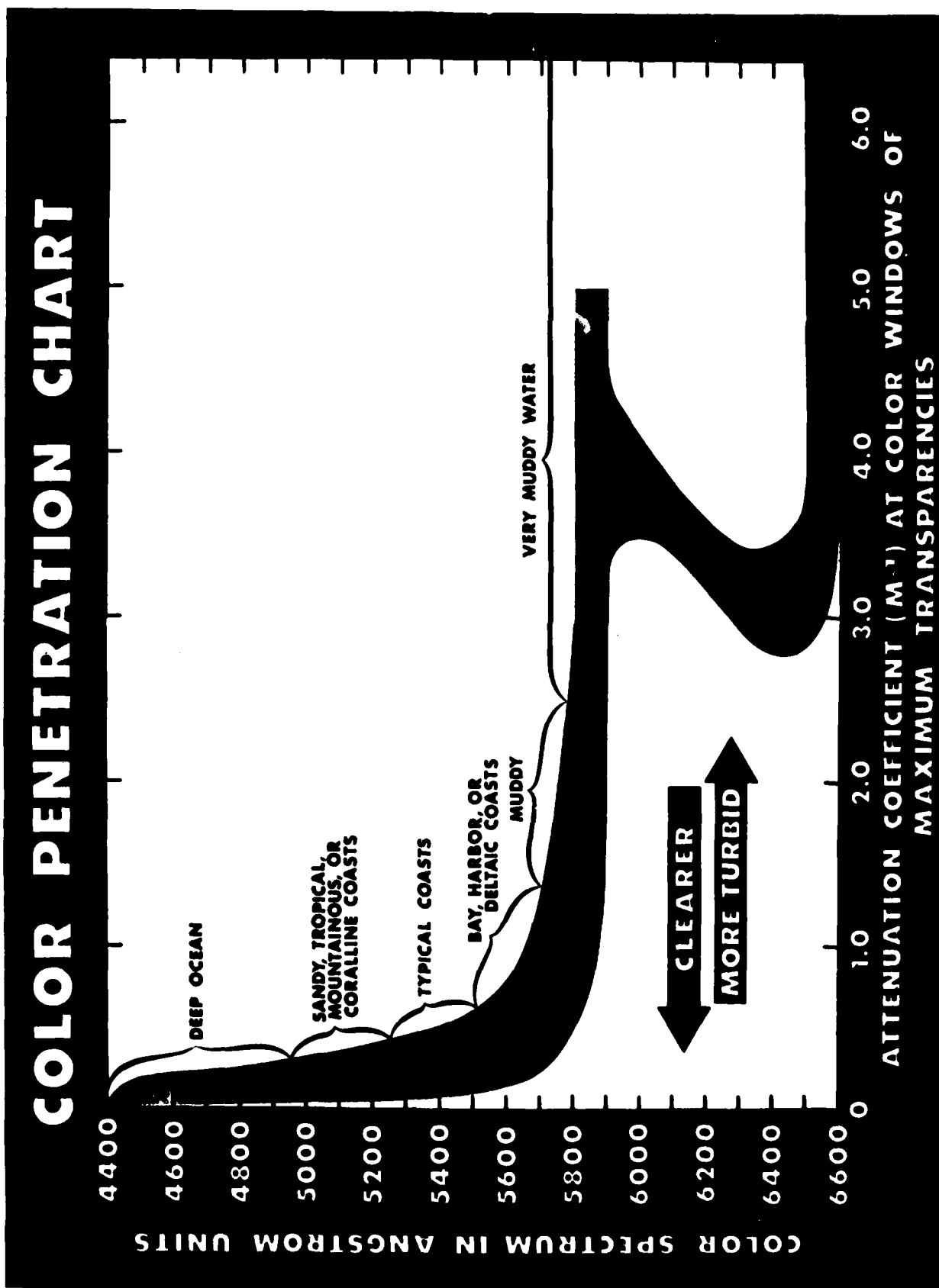in dielectric constant and aspect angle. Sudden changes from dry

COLOR PENETRATION CHART

Figure 15

-46-

to wet surface, or sharp changes in terrain, maximize the amount
that can be seen on a radar image. Microwave radiation has
negligible ability to penetrate water, and therefore no submarine
detail is observed.

Since coastal areas are frequently flat and low-lying, radar
data may be expected to show land/water boundaries in great detail,
but to provide no detail in the water, and to show land detail
only due to changes in surface (such as from agriculture to urban,
plowed soil to fallow soil, etc.). There is one exception to this
statement. The SEASAT spacecraft was designed to permit the study
of sea state. If there is a strong wind blowing at the time of
image acquisition, radar images will show the direction of those
winds through shadowing of water areas to the lee of the shore.
Examples of this are shown in Section VI. An example of the value
of SEASAT SAR images in an area with good surface geological
exposure is given in Figure 16. Interpreter assessment of this
image places the effective ground resolution in the 50 meter range.
Data of this type and resolution will therefore add to the inter-
pretations made from Landsat MSS data only if a phenomenon is
distinguished by its microwave reflectance and not by its visible
or near-IR reflectance.

FIGURE 16
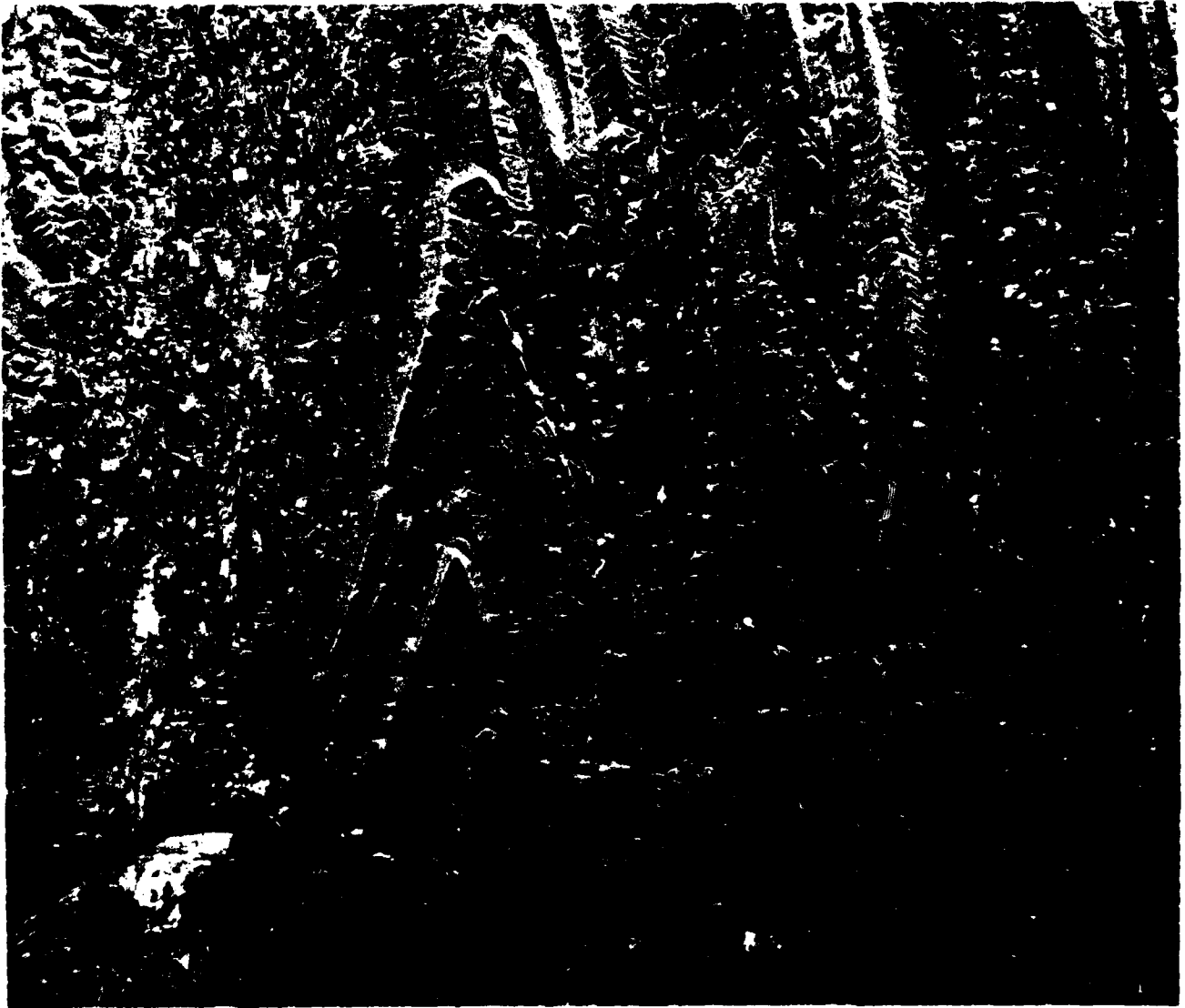
V. SELECTION OF TEST AREAS

The selected test areas for interpretation in this study are
centered on the towns of Elizabeth City, North Carolina and Duck,
North Carolina, with the Elizabeth City test site as the primary area
for analysis. The available data for the Elizabeth City test area
is as follows:

(1) Landsat MSS digital tapes

(2) SEASAT full resolution SAR digital tape

(3) 1:20,000 scale panchromatic black and white
photography

(4) 1:20,000 scale color infrared photography

(5) 1:112,000 scale side-looking airborne radar

(6) 1:9,300 scale thermal infrared film

(7) 1:62,500 maps, from the 1940 to 1948 period

(8) Ground truth photography and associated descriptive
material (1980 survey)

(9) Soil survey of Pasquotank County, North Carolina

The list of materials for the Duck, North Carolina area consists
of:

(1) Landsat MSS digital tapes

(2) SEASAT full resolution SAR digital tape

(3) 1:62,500 maps, from the 1940 to 1948 period

(4) 1:12,000 scale panchromatic black and white photography

(5) 1:2,000, 1:5,000, and 1:10,000 scale color infrared photography.

VI. INTERPRETATION RESULTS USING LANDSAT AND SEASAT DATA IN SELECTED TEST AREAS

A. Processing

Windows for the Elizabeth City and Duck test areas were identified on a 1:250,000 scale SEASAT image. Using a 1:1,140,000 Landsat GEOPIC print (Figure 17), appropriate row and column numbers for the Landsat CCT were calculated, and test area locations verified by display on a Grinnell interactive system (see Appendix 1 for Grinnell description). After inspection and contrast adjustment of the color images (Bands 4, 5 and 7) on the screen, 35 mm photographs were taken and developed to an approximate 1:250,000 scale. Initial interpretation utilized these photographs (Figure 18).

For the same selected windows, GEOPIC products were developed at a scale of 1:100,000, and a GEOPIC image of the whole scene using Bands 4, 5 and 7 was processed at 1:250,000. After image processing, comparison of the 1:100,000 scale windows with the 1:250,000 scene showed that greater feature size was gained at the expense of clarity in the large scale image. All subsequent interpretation was therefore performed using the 1:250,000 scale image (Figure 19).

B. Interpretation

A complete initial interpretation of the test areas was performed using the Landsat data alone. Following this, interpretation was made of the SEASAT SAR image test areas (Figure 20) to determine what additional information could be added to the Landsat data base. It would be misleading to conclude that features more visible on the SEASAT SAR image reflect the result of increased spatial resolution.
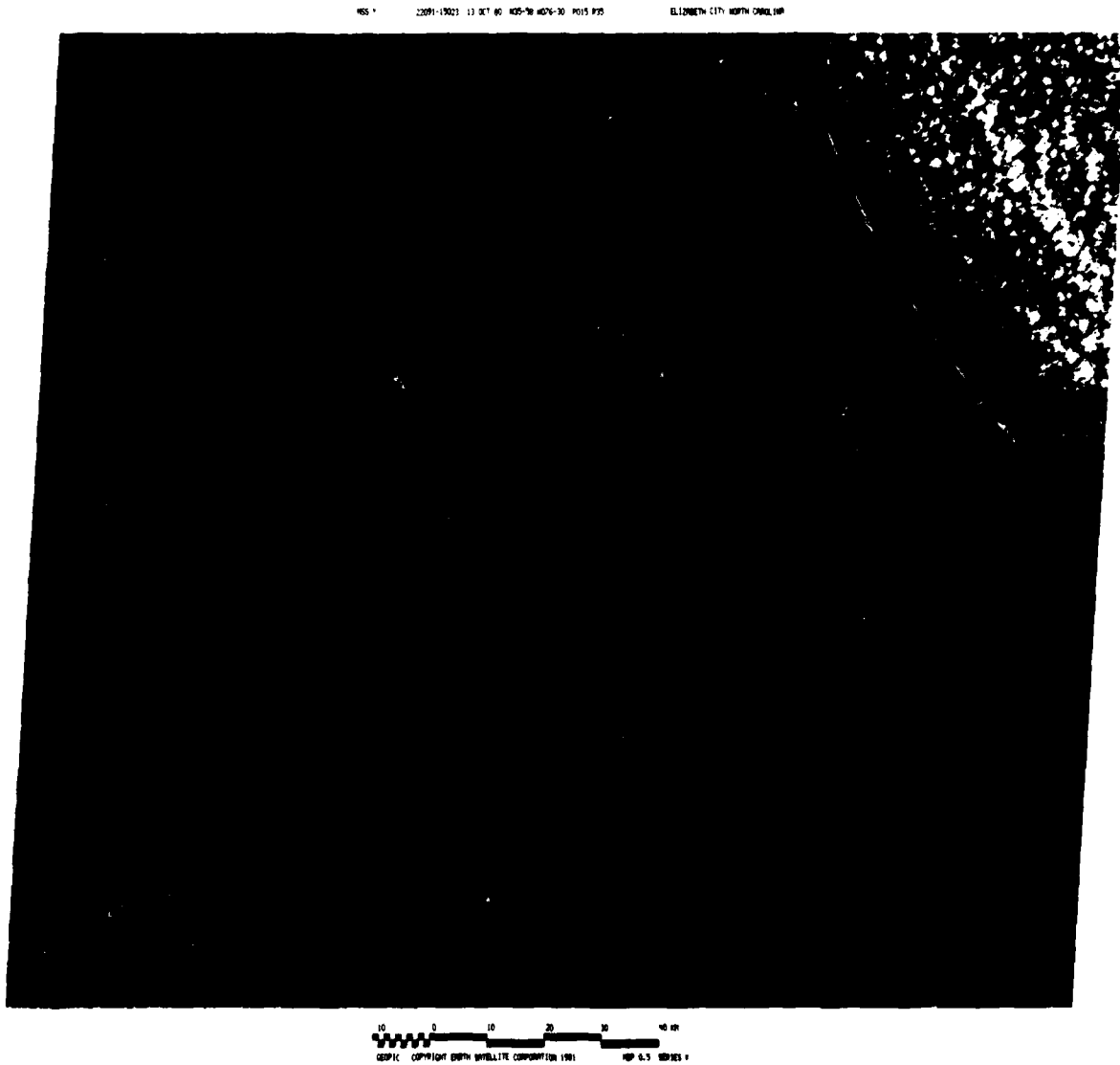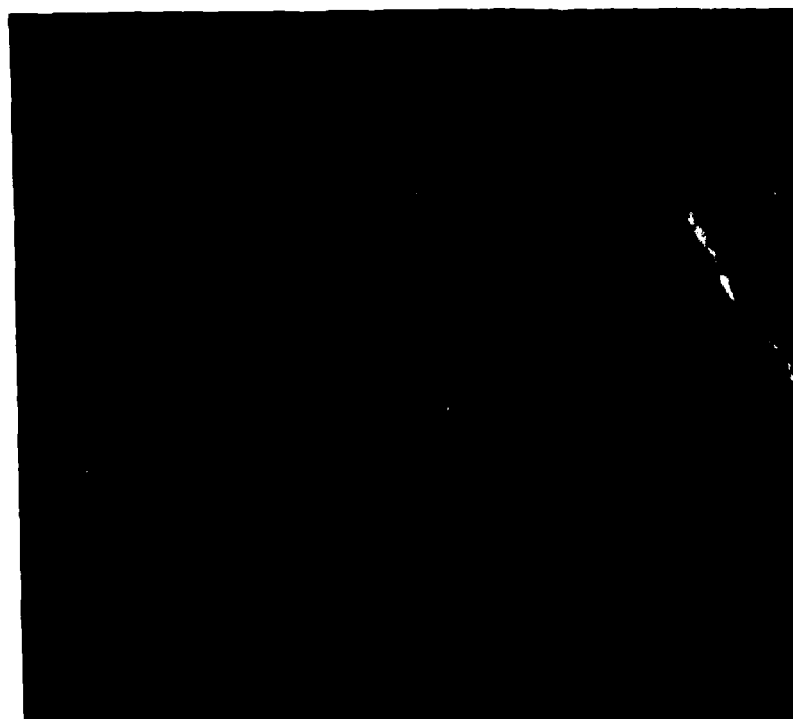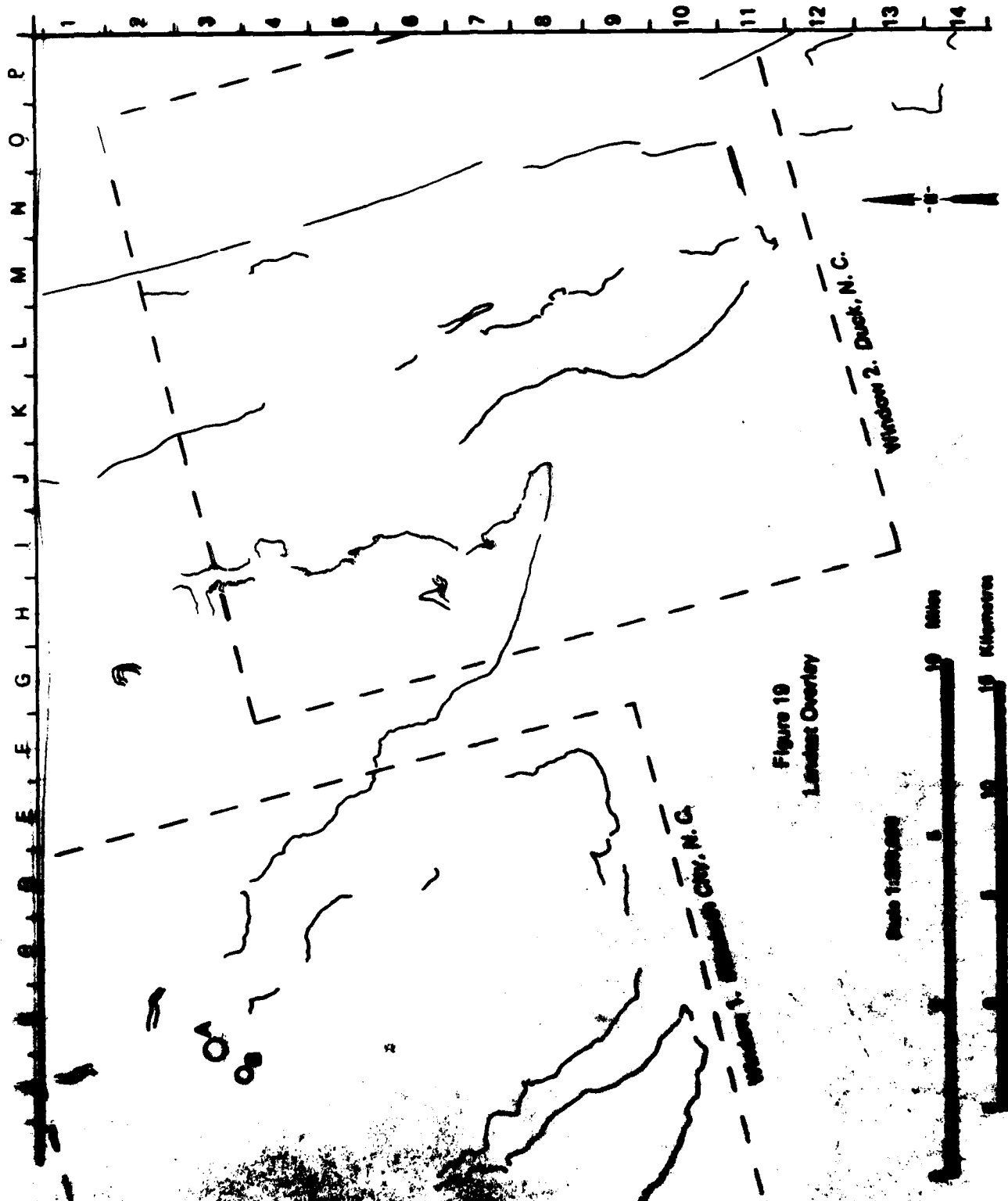
FIGURE 17

FIGURE 18

Figure 19
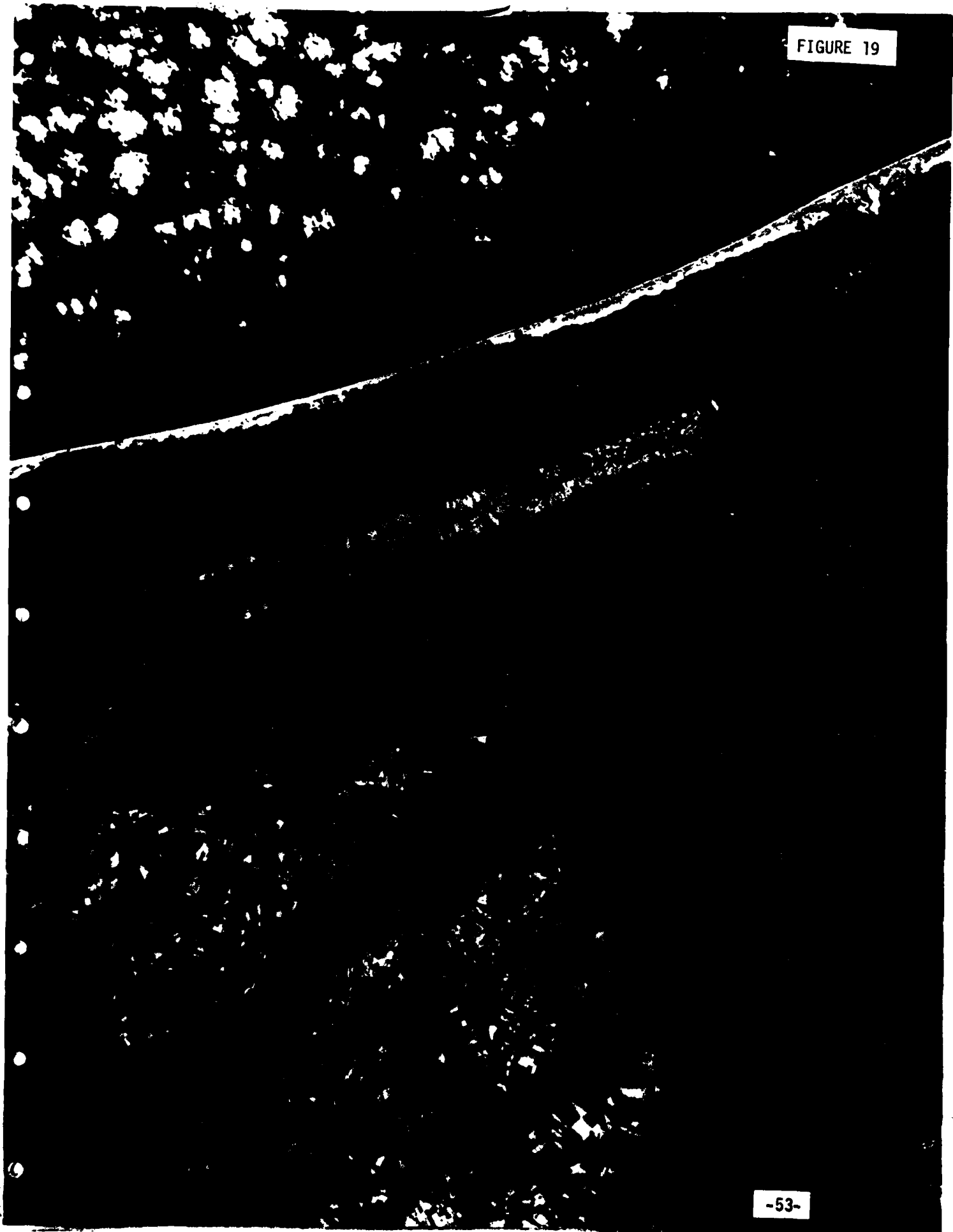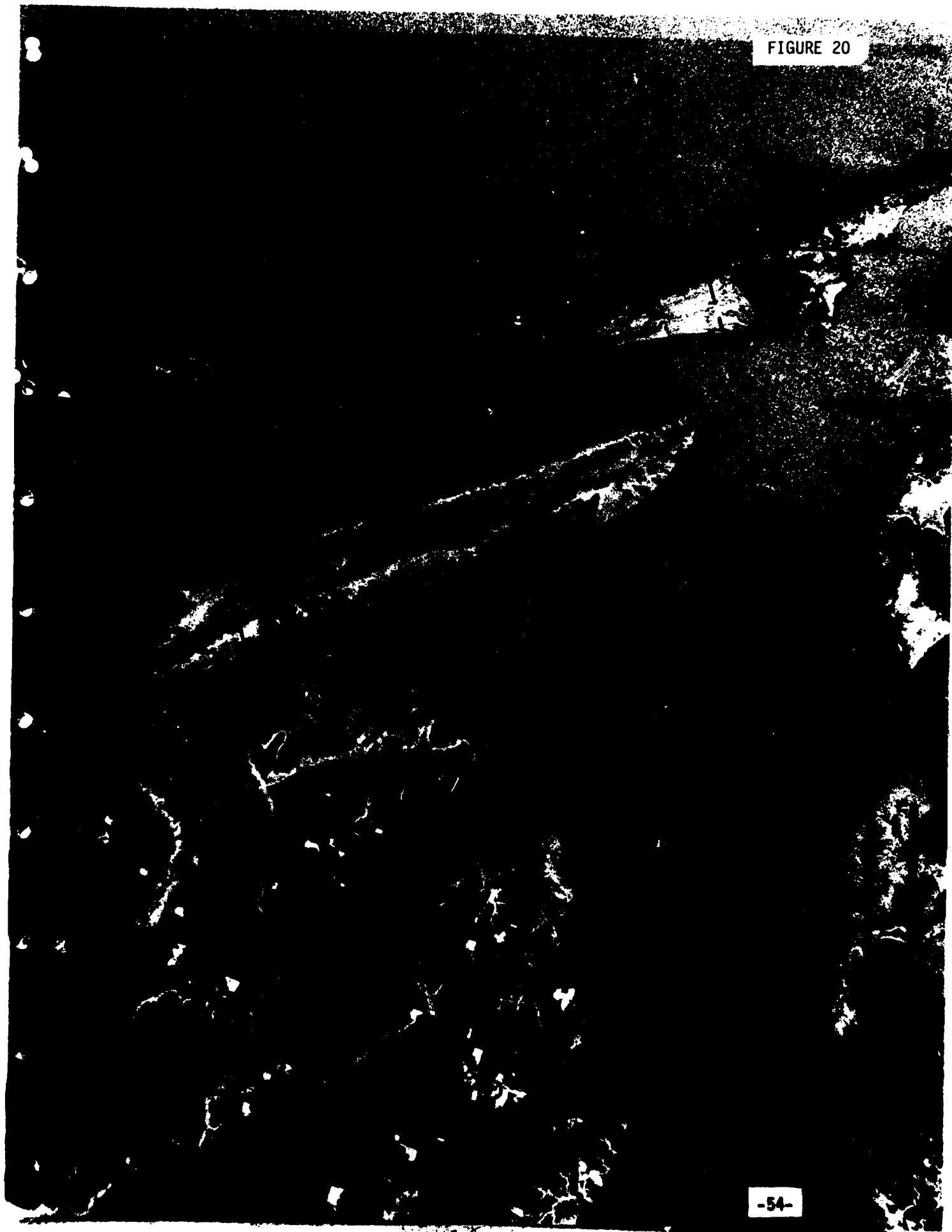Lambert Overlay

Window 2. Duck, N.C.

LH 2030

FIGURE 19

-53-

FIGURE 20

The examples on the SEASAT image where contrast is sufficient to permit improved resolution over Landsat are few in number. Generally for these test sites, the high spectral resolution provided by Landsat allows visibility of land use classes and features which are less distinct or undetectable with SEASAT.

However, the addition of SEASAT SAR data provides valuable information based on surface texture, aspect angle, and change in dielectric constant. When these characteristics are more prevalent than spectral differences, features will be more easily detected on the SEASAT image.

The data sources complement each other and provide more information together than either does separately.

Results of the image interpretations follow, discussed by feature category. Overlays to Figures 19 and 20 for the Landsat and SEASAT images are referenced in the text to illustrate specific features. A summary of the most pertinent results is found in Table 3. SEASAT SAR interpretation was performed using an image without final range correction; however, the small size of the test areas compared with the total image size permits comparison of Landsat and SEASAT with little effect of distortion.

WATER PENETRATION & SEDIMENT FLOW

Maximum light transmittance in clear ocean water occurs in the spectral range between .44 - .54 μm. In more turbid waters or those containing dissolved organic matter, the range of maximum

Table 3

INTERPRETATION OF TEST AREA IMAGES

Level of Feature Identification 1:250,000 Scale	Landsat MSS	SEASAT SAR
I. Feature is distinctly visible and readily identified; configuration nearly certain.	A.1. Shoreline configuration: tidal inlets, inland waterway. B.1. First order land cover classification and borders, such as wetlands, forest, agricultural fields, sand dunes. 2. River and stream drainage to primary tributaries. 3. Agricultural field differentiation. C.1. Clearings through forest areas for roads/railroad tracks (indistinguishable). 2. Bridges over large water bodies.	A.1. Delineation of land/water interface, especially in areas of mud flats and small islands. B.1. Rivers near the mouth and primary tributaries. 2. River valleys, stream drainage patterns to tertiary tributaries- illustrated by extent of riparian vegetation.
II. Feature is clearly visible and can be identified; fairly certain of configuration or characteristics.	A.1. Water current-derived landforms, e.g., points, ridges and swales from barrier beach tides. 2. Configuration of mudflats and islands, and vegetation variations within. B.1. Vegetation at or just below water surface (indistinguishable). 2. Currents in shallow, sediment-laden water. 3. Sediment outflow from rivers and agricultural areas. C.1. Isolated urban features surrounded by contrasting land cover, e.g., airport. 2. Agricultural fields to a minimum of approximately 11,000 sq. meters.	A.1. Vegetation on or just below water surface (indistinguishable). 2. Sand dune form, ridges and swales. 3. Agricultural fields to approximately 9,000 sq. meters.

Level of Feature Identification 1:250,000 Scale	Landsat MSS	SEASAT SAR
III. Feature is identifiable; characteristics blurred or indistinct.	A.1. Mudflat/water interface. 2. Zone of swash and/or shallow shore slope (indistinguishable). B.1. Secondary and tertiary stream drainage (forested areas). 2. Density of settlement patterns on urban areas and barrier islands: road grids, building clusters, aggregated land structures associated with port or harbor. C. Small bridges over rivers and intracoastal waterway.	A.1. Densely built up urban areas and transition to other land uses. 2. Rough textured and/or recently irrigated fields. 3. Agricultural field differentiation.
IV. Feature is detectable; interpretive inference required for identification.	A.1. Sources for water spectral differences: sand, sediment, subsurface vegetation. B.1. Canals and irrigation ditches through forested and farmed areas. 2. Roads through agricultural areas.	A.1. Pier and harbor structures abutting into water. ITEMS IN IV AND V BELOW ARE LESS VISIBLE ON SEASAT: B.1. Large scale (<23.5 cm) water patterns. 2. Single urban features: bridges, roads.
V. Not detectable.	A.1. Secondary and tertiary stream drainage through agricultural regions.	A.1. Water depth or sediment, small currents. B.1. Airports or other flat areal features. 2. Canals, irrigation channels.
VI. Not detectable on either image.	A.1. Individual urban features where they are clustered. 2. Railroad bridges over water. B.1. Streams through urban areas. 2. Small islands (100 m or less).	

transmittance shifts to longer wavelengths. Maximum penetration
of marine water in a marsh environment occurs in the wavelength
span of .55 - .63 µm, which closely corresponds to MSS Band 4 of
Landsat.

Reflectance of scattered radiation in water bodies reveals
sediment patterns and/or near-shore ocean bottom. This is illus-
trated in Figure 19 from M1 to O11. In order to determine which
feature is being viewed a time series of images is required, since
the signature cannot be positively identified on one image.
Repeated coverage of the area will show whether shifting beach
sediments or more stationary shore slopes are being revealed.
Shallow water currents and sediment contribution from adjacent
agricultural fields may also be monitored in this way. An example
of the latter is seen at F7 on Figure 19.

Sediment from various sources can be differentiated on
Landsat images based on spectral signature and inference from
location. Turbidity near sandy beaches, once positively identified,
will exhibit a very strong reflectance and a light tone on the
image (O8 on Figure 19). This changes to a darker pattern near
river mouths and marshes where sediment tends to contain more mud
(K3 on Figure 19).

Sediment flow helps to illustrate water currents. For this
reason, on Landsat images, current patterns are much less visible
in deeper water. Circulation in deep water areas surrounded by
more shallow water can be inferred, however, by the adjacent near-
shore patterns (M13 and H14 on Figure 19).

On the SEASAT image, water agitation at a scale greater than the wavelength of the radar signal (23.5 cm) can be detected, providing an idea of the gross surface currents and texture.

Dark patches are visible in the more shallow water near shore (I1 and L1 on both images). After initial inspection of the Landsat image, it was thought that these might be areas of surface vegetation growth or deeper, less turbulent water with little sediment. Comparing the Landsat and SEASAT SAR data revealed that this was not the case. Since the radar signal does not penetrate water, corresponding areas of low reflectance on the SAR image imply that the phenomenon is surficial, and that the water surface in the dark patches *must be* smooth. It was concluded that the patterns result from mud flats or aquatic vegetation just below the water surface. The vegetation is manifested on the Landsat image as a darker signature and on the SEASAT image as an area of smooth water (low reflectance) resulting from increased friction near the surface. This is an excellent example of the complementarity of MSS and SAR data and the insights that can be gained by their combined use.

SHORELINE & INLET FEATURES

Both Landsat and SEASAT images exhibit high resolution of shoreline and inlet features (I4 on both images). Although wind shadow may cloud some shoreline subtleties, SAR supplies additional feature visibility in marsh or island areas. Subtle shoreline characteristics are visible where low marsh/water spectral differences

may have muted them on Landsat imagery (M6 on Figure 20).
Isolated islands 100 meters or less in diameter, readily dis-
cerned on panchromatic aerial photography, are not visible on
either the Landsat or SEASAT image.

SAR ability to detect even slight topographic differ-
ences is also seen in the improved detection of sand dune con-
figuration (09 on Figure 20). Landsat provides detail of
vegetation variation on the dunes and within marsh areas.

STREAM DELINEATION

Stream and river delineation is also enhanced by the con-
current use of MSS and radar data. As seen in C6 and C9 of
Figure 19, inlets, rivers, and their primary tributaries are
distinctly visible on Landsat imagery. However, smaller tribu-
taries of inland drainage, especially those occurring in
agricultural areas, become difficult or impossible to detect due
to low spectral variation between agricultural fields and the
narrow strip of riparian vegetation.

In addition to river delineation, SAR imagery clearly
illustrates river valleys and stream drainage patterns to the
level of secondary and tertiary tributaries (B4 to C7 on
Figure 20). This high return results from surficial dielectric
properties associated with high moisture levels in riparian
vegetation, and also its relative surface roughness. The same
response is visible from scattered agricultural fields such as
in C2 in Figure 20. This additional data is especially useful

for drainage patterns through agricultural or densely forested regions, where MSS information is often muted or lost. Stream drainage through urban areas is not visible with either medium.

URBAN AREAS & FEATURES

Individual features in urban areas are not readily identified on either the MSS or SAR imagery, unless they are isolated amid a background of high contrast, spatially or texturally. The airport at C5 on Figure 19 is quite obvious on the MSS image but is lost altogether on SEASAT due to its smooth texture. For the same reason, small linear features such as roads, small bridges, canals, and irrigation channels are not visible on SEASAT, despite the theoretical 25 meter resolution.

An exception to this occurs where linear features extend into water. Thus, Elizabeth City harbor features are detectable within circle A on SEASAT (Figure 20). The bright spot in the water above may be a ship or barge. The 610 meter Duck FRF pier can be seen at O7 on Figure 20 and a smaller fishing pier is visible within circle B.

These features are not visible with Landsat, which provides better detection of inland linear patterns. Canals and/or irrigation channels are intermittently visible (I8 on Figure 19) where they pass through forested areas. This is also true for roads (B3 on Figure 19) and railroad tracks (B2 on Figure 19) which are visible but indistinguishable where they cut a swath through forest lands. These features are lost where they traverse urban or agricultural land cover. The intracoastal waterway is clearly seen (I2 on Figure 19)

and small bridges over water may also be detected. The
Pasquotank River bridge within circle A on Figure 19 is approxi-
mately 115 meters long.

General urban settlement patterns are seen on both images
but again the information differs. The main auto routes through
Elizabeth City are visible by inference on Landsat where spectral
differences of paved and built surfaces cause the linear pattern
to stand out from the surrounding land cover (A3 on Figure 19).

Similarly, general road grids are visible in the surround-
ing residential areas. Delineation of urban land use is unclear
with Landsat where merging of land cover makes borders indistinct.
SAR data is even less reliable for urban/non-urban separation,
since outside the high reflectance area of inner city and docks,
no urban/non-urban transitions can be observed on the image (A3
on Figure 20). Combining data from both images provides detailed
information on urban settlement density patterns.

AGRICULTURAL PATTERNS

Transition between other land classifications is not as
clearly seen on SAR as on MSS imagery. The boundaries between
agricultural land and forest are indistinct, and identification
of different field types is even more difficult. Although direct
comparison of field conditions cannot be made between the images
since they were taken during different seasons and years, the
high spectral response of Landsat provides superior resolution

of field/forest patterns and agricultural field types. The
fallow (blue) field located within circle B on Figure 19 is
approximately 106 meters on each side and illustrates the
minimum field size which can reasonably be delineated. Distinc-
tion between recently cleared fields (white) and those covered
by crops in different growth stages (various shades of red) is
readily made.

In this respect, contrast on the SEASAT image is much
poorer and fields which can be confidently delineated are generally
larger than on Landsat. The field in circle C of Figure 20 has
approximate dimensions of 515 meters x 230 meters. In areas of
high contrast, fields smaller than those visible on Landsat can be
resolved, as in circle D on Figure 20 where each side of the field
is approximately 95 meters.

Examples on SEASAT imagery where contrast allows resolution to
this level are very few, and generally visibility on this SAR image
is reduced as compared with the spectral contrast of Landsat. How-
ever, the images used in tandem provide much more information than
either does separately. Features best delineated on MSS imagery are
those which possess considerable spectral variation such as land/
water interfaces and areas of differing vegetation. Landsat resolu-
tion is good for shorelines, land cover variations of forest, wet-
lands, and agriculture, and, to a lesser extent, urban areas.
SEASAT augments Landsat data in areas of marsh/water interface,

stream drainage through varying land cover, urban development

patterns, and coastal abutments. Additionally, new information

can be gained about many features by adding SAR data, with its

indicators of angle, surface texture, and moisture content,

to the spectral characteristics provided by Landsat. Thus,

although the spatial resolution of this SEASAT image does not

approach the theoretical 25 meters, its unique characteristics

add useful information to a Landsat data base.

VII.   CONCLUSIONS

The principal conclusions to be drawn from the work of this project
are as follows:

(1) Both Landsat MSS and SEASAT SAR data are useful in providing a
     broad overview of coastal configurations, borders and land cover
     classifications. Neither data source is capable of providing
     the level of detail available from either panchromatic or color
     aerial photography, and cannot be regarded as a substitute for
     the latter.

(2) If one were forced to choose one data source, either Landsat MSS
     or SEASAT SAR, to apply to civil works programs, that choice would
     be Landsat MSS. In principle, the superior spatia' resolution of
     the SEASAT data should compensate for the superior spectral nature
     of the Landsat MSS data. In practice, the SEASAT SAR data does
     not look any better in spatial resolution than the Landsat MSS data.
     Rather than being 25 meters, as the specifications for full resolu-
     tion SEASAT SAR data suggests, the images analyzed on this project
     appear to be of a resolution no better than 75 to 100 meters.

(3) Despite the point made in (2) above, there are significant advan-
     tages to employing MSS and SAR data in concert. As Table 3 of
     Section VI clearly revealed, a number of features, particularly
     those relating to land/water interfaces, are more readily visible
     on SEASAT SAR data. The two data sources together are stronger
     and more reliable than either taken separately.

(4) The results obtained from this study leave uncertain the value
of increased spatial resolution data <u>in the Landsat wavelength
range</u>. The physical variables measured by the SEASAT SAR and
Landsat MSS imaging systems are radically different. The only
realistic way to evaluate the Thematic Mapper data is through
the use of a data source which senses in the same or similar
wavelength regions.

(5) Enhancement processes both for Landsat and SEASAT data have a
huge effect on the interpretability and therefore the value of
remotely sensed information. It is likely that the pre-processing
which had already been applied to the SEASAT data had lost enough
information to make a true test of the potential of that data source
impossible. The degree of detail visible on the collateral air-
borne radar images used for confirmation results on this project
re-emphasize the power of high resolution radar data as an inter-
pretive tool, even in areas without significant terrain relief. A
higher resolution spaceborne radar instrument should be a tool of
great value in coastal mapping.

VIII.   RECOMMENDATIONS FOR FUTURE SIMULATIONS

The best practical way to evaluate the potential of Thematic Mapper data from Landsat-D is via the calculated degradation and subsequent analysis of high resolution airborne scanner data with the same spectral bands as the Thematic Mapper. A number of overflights of the U.S. in non-coastal areas have been made by aircraft carrying a multispectral scanner with frequency ranges equal to those of the Thematic Mapper. Following pre-processing to remove wide angle effects associated with the much lower altitude of the aircraft compared with the spacecraft, the data can be degraded to match the 30 meters expected of the Thematic Mapper. Analysis of this data source avoids the main problems (of image registration, and of compatibility of spectral bands) that caused difficulties in performance of this project.

We recommend that a flight of an airborne Thematic Mapper Simulation Scanner be considered over the same test areas as Elizabeth City and Duck, North Carolina. The completeness of the data base, as itemized in Section V of this report, suggest that all the tools are at hand for a very thorough and informative analysis of the simulated Landsat-D data.

Although the launch of Landsat-D is now only one year away, the suggested simulations are still worth performing, since the Landsat-D data stream for the Thematic Mapper is not projected to become operational at reasonable scene volume until 1984 or 1985.

The Thematic Mapper also contains spectral channels (1.55 - 1.75 micrometers and 2.08 - 2.35 micrometers) that should be of great value in mapping of clays and silts. It is recommended that experiments be undertaken to concentrate on the possible value of these two channels.

-67-

Nothing in the present experiments using Landsat MSS or SEASAT SAR gives

any indication as to the information content of these longer wavelength

infrared channels. The same degraded resolution airborne scanner data

would allow an assessment of the value in civil works of these new spectral

bands.

The existing ground truth for the North Carolina test sites is

detailed enough to allow an excellent evaluation of new data sources,

whether through simulation of Landsat-D data or otherwise. It is

recommended that the value of this collateral data base be emphasized,

and suitable use be made of it in subsequent experiments evaluating

remotely sensed data.

REFERENCES

1. ERTS Data Users Handbook; Goddard Space Flight Center (1972, with updates)

2. Landsat Data Users Handbook; Goddard Space Flight Center (1972, with updates)

3. Sherman, J.W., Report on the Conferences on the National Oceanic Satellite System; Appendix E and F. U.S. Department of Commerce (September 1980)

4. Landsat-D Operational Quality Assurance/Performance Evaluation Review; Goddard Space Flight Center User Needs Review (February 11, 1981)

5. SPOT Satellite-Based Remote Sensing System; Centre National d'Etudes Spatiales brochure (February 1981)

6. Preliminary Stereosat Mission Description; Jet Propulsion Laboratory Report 720-33 (May 30, 1979)

7. Anglin, R. L., Stereosat: A Proposed Private Sector/Government Joint Venture in Remote Sensing from Space; JPL Publication 80-70 (August 1, 1980)

8. Haralick, R.M., Caspall, F.C., and Simonett, D.S., 1970, Using Radar Imagery for Crop Discrimination: A Statistical and Conditional Probability Study: Remote Sensing of Environment, v. 1, no. 2, p. 131-142.

9. Manual of Remote Sensing, Vol. II, American Society of Photogrammetry, 1975, Chapter 14 - Fundamentals of Image Interpretation.

10. Jet Propulsion Laboratory, Radar Geology: An Assessment; JPL Publication 80-61 (September 1, 1980)

11. Ford, J. P., et al, Seasat Views North America, the Caribbean, and Western Europe With Imaging Radar; Jet Propulsion Laboratory; JPL Publication 80-67 (November 1, 1980)

12. Bryan, M. L., Analysis of Two SEASAT SAR Images of an Urban Scene; Paper presented at the American Society of Photogrammetry Annual Convention, Washington, D. C. (February 1981)

APPENDIX 1

Reference was made in the main text to the GEOPIC image products,
and to the Grinnell interactive system. These are described in summary
here. GEOPIC takes Landsat MSS data, computer processes it to perform
radiometric and geometric corrections, performs contrast adjustment and
edge enhancements under direction from the Grinnell, and photoprocesses
the resulting enhanced images. The system of programs to perform these
manipulations of the data runs on a Prime 456 minicomputer, with 512K
of main memory, 332 megabytes of disk storage, two 75 IPS tape drives,
and a Grinnell 270 interactive display device.

The Grinnell 270 permits the storage and display on a TV screen of
four 512 x 512 image windows, with an ability to extract and statistically
analyze any subarea of the window using a joystick and movable cursor to
control area selection.

The general processing consists of the following stages:

(1) Employing as input Landsat MSS computer compatible tapes,
pre-processing of the full image is performed for radio-
metric and geometric corrections.

(2) Extraction of image statistics is performed, either for
a full scene or for a selected area (for example, by using
the Grinnell, it is possible to identify particular land
or water areas for which statistics are to be developed).

(3) From the computed image statistics, optimized contrast
adjustments are generated, and the full image is then
enhanced by application of these adjustments.

(4) The resulting images are checked, in whole or in part, by
re-display on the Grinnell screen.

(5) If required, stages (2) through (4) are repeated until a satisfactory image results. An output tape is then created.

(6) The output magnetic tape from the Prime/Grinnell system is read by an Optronics P1500 tape-to-film writer, which converts pixel grey levels to grey tones on a black and white film. For each spectral band, the Optronics is used to generate a black and white 9" x 9" positive transparency.

(7) Three black and white positives (for Landsat MSS, Bands 4, 5 and 7 are used for a standard false color GEOPIC product) are registered, a contact scale color negative is developed, and final prints at any required scale are produced using photographic enlargement.

In addition to the standard products, the GEOPIC system also permits the production of digital ratio images, digital scene enlargement, principal component images, and scene multispectral classification. The general procedure to produce each of these products is identical to that described in steps (1) through (7) above, and each begins from the same input Landsat MSS computer compatible tape.

END

DATE
FILMED

3-82

DTIC